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ROCKWELL INTERNATIONAL
NORTH AMERICAN SPACE OPERATIONS
ROCKY FLATS PLANT

Remedial Investigation Report for High Priority Sites

(881 Hillside Area)

Volume I

U.S. DEPARTMENT OF ENERGY

Rocky Flats Plant
Golden, Colorado

1 MARCH 1988

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Section 1.0

1.0 EXECUTIVE SUMMARY

This report presents the results of the remedial investigation of the 881 Hillside Area at the Rocky Flats Plant, Golden, Colorado. The objectives of the remedial investigation are to verify the existence and location of the waste disposal sites, to characterize the sites, to evaluate the nature and extent of contamination, and to develop data needed for feasibility studies of remedial alternatives as appropriate.

The Rocky Flats Plant is a Department of Energy (DOE) facility manufacturing components for nuclear weapons and has been in operation since 1951. The Plant fabricates the components from plutonium, uranium, beryllium, and stainless steel. Both radioactive and nonradioactive wastes are generated in the process. Current waste handling practices involve on-site and off-site recycling of hazardous materials and off-site disposal of solid radioactive materials at another DOE facility. However, both storage and disposal of hazardous and radioactive wastes occurred onsite in the past. Preliminary assessments under the DOE Comprehensive Environmental Assessment and Response Program (CEARP) identified some of the past on-site storage and disposal locations as potential sources of environmental contamination.

CEARP investigations at Rocky Flats Plant have been integrated with other RCRA and CERCLA issues pursuant to the Compliance Agreement between DOE, the U.S. Environmental Protection Agency (EPA) and the State of Colorado (Colorado Department of Health), dated July 31, 1986. The Compliance Agreement addresses hazardous and radioactive mixed waste management at Rocky Flats Plant. The

CEARP Phase 1 Installation Assessment for Rocky Flats Plant included analyses of current operational activities, active and inactive waste sites, current and past waste management practices, and potential environmental pathways through which contaminants could be transported. CEARP Phase 1 identified a number of sites that could potentially have adverse impacts on the environment. Data collected during preparation of the RCRA Part B Operating Permit Application identified several additional potential sites. All potential sites at Rocky Flats Plant were designated as solid waste management units (SWMUs).

Hydrogeological and hydrogeochemical characterizations of the entire Rocky Flats facility were performed in 1986 as part of the initial CEARP site characterization. Results of that investigation are presented in the RCRA Part B Permit Application for the Rocky Flats Plant. Analysis of these data has identified four areas which are the most probable sources of environmental contamination, with each area containing several sites. These areas are the 881 Hillside Area, the 903 Pad Area, the Mound Area, and the East Trenches Area. Sites on the 881 Hillside Area were selected as high priority sites because of the high concentrations of volatile organic compounds detected in ground-water, the relatively permeable soils and the Area's proximity to a surface water drainage.

The CEARP remedial investigation of the twelve sites comprising the 881 Hillside Area began in March 1987. The investigation consisted of the preparation of detailed topographic maps, radiometric and organic vapor screening surveys, surface geophysical surveys, a soil gas survey, a boring and well completion program, soil sampling, and ground and surface water sampling. A brief summary of the findings at each site is presented below:

1. Oil Sludge Pit (SWMU 102) -- A small pond located south of Building 881 was used for disposal of oil sludges in the late 1950s. Isolated detections of tetrachloroethene (PCE) were found in the vicinity of the SWMU in the soil gas survey. In addition, pthalates were found in the soils.

2. Chemical Burial Site (SWMU 103) -- A small pit was used for disposal of liquid wastes southeast of Building 881 in the early 1960s. PCE was detected in soil gas and acetone, 2-butanone and pthalates were detected in soil samples in the area.

3. Liquid Dumping (SWMU 104) -- An area east of Building 881 was reportedly used for disposal of unknown liquids prior to 1969. No evidence of the area was found in review of historical airphotos or in the field investigations.

4,5. No. 6 Fuel Oil Tanks (SWMUs 105.1 & 105.2) -- Two fuel oil tanks are located south of Building 881; they are out of service and filled with concrete. No evidence of contamination was found near the tanks and they have been removed from consideration as potential sources of environmental degradation.

6. Outfall Site (SWMU 106) -- An overflow line from the sanitary sewer sump south of Building 881 daylights on the slope below the Building. Soils in the vicinity were found to contain methylene chloride, acetone, 2-butanone and phthalates.

7. Hillside Oil Leak (SWMU 107) -- Oil was discovered flowing from the Building 881 footing drain in early 1973. The source of the oil was never positively identified but the oil was collected in a skimming pond and transported offsite. PCE, 1,1,1-trichloroethane (TCA), trichloroethene (TCE) and dichloroethene (DCE) were detected in soil gas in the vicinity of the SWMU. The on-going discharge of water from the footing drain was found to contain low concentrations of several volatile organic compounds and low concentrations of organic compounds were found in soils.

8,9. Multiple Solvent Spills (SWMUs 119.1 & 119.2) -- Two areas east of Building 881 were used for barrel storage between 1969 and 1972. PCE and TCE were found in soil gas and several volatile organic compounds and phthalates were found in soils near the SWMUs.

10. Radioactive Site (SWMU 130) -- Soils contaminated with low levels of radionuclides were place on the hillside east of Building 881 and covered with soil between 1969 and 1972. Methylene chloride and bis(2-ethylhexyl)phthalate were found in soil samples at the site of the SWMU. No radionuclides were found in the soils.

11. Sanitary Sewer Line Leak (SWMU 145) -- The sanitary sewer line leaked on the hillside southwest of Building 881 in early 1981. Although the line may have carried low levels of radionuclides approximately eight

years before the leak, there is no evidence to suggest that any environmental degradation has resulted from the leak. SWMU 145 is deleted from further consideration.

12. Drum Storage Area (SWMU 177) -- Building 885 is currently used for satellite collection and 90-day accumulation of RCRA regulated wastes. The building will be closed under RCRA Interim Status (6CCR1007-3). Complete information on this unit is provided in the RCRA Closure Plan.

Ground water conditions were evaluated at the Hillside in general and in detail near SWMUs suspected as potential sources of ground-water contamination based on the nature of the SWMUs and geophysical and soil gas surveys. Low levels of volatile organic contamination were found south of Building 881 in the general vicinity of SWMUs 103, 106 and 107 and much higher levels were found at SWMU 119.1. The extent of volatile organic contamination has been bounded by the investigation and is relatively small, probably because the soils are generally clayey with discontinuous lenses of more permeable materials and because the quantity of ground-water flow is consequently small. In addition, total dissolved solids, nickel, selenium, strontium and uranium are elevated with reference to chemical conditions west of the plant in the shallow ground water, possibly as a result of natural geochemical variability or leaching by waste products. The concentrations of these elevated constituents are relatively low. Degraded ground-water quality occurs only in the shallow flow system; the bedrock ground-water quality has not been impacted. In addition, only very slight elevations of TDS and strontium are indicated downgradient of the 881 Hillside in the valley fill alluvium of Woman Creek; volatile organics were not detected in the Woman Creek alluvium.

Surface water in the South Interceptor Ditch upstream of the Hillside contains slightly elevated uranium concentrations. Volatile organics are not considered to be a problem in any surface waters except for the discharge from the Building 881 footing drain. The chemistry of surface water downstream of the Hillside in Ponds C-1 and C-2 is equivalent to background conditions and it is concluded that there is not a surface water contamination problem associated with the 881 Hillside.

Ambient air monitoring for radionuclides and Criteria Pollutants (total suspended particulates, ozone, sulfur dioxide, carbon monoxide, nitrogen dioxide and lead) during the past ten years and during the remedial investigation indicates that air quality is not degraded by operations at the Plant. In addition, an ambient air survey during the remedial investigation did not detect any volatile organics emanating from the areas.

Biota at the Plant have been identified, classified, and studied with respect to plutonium uptake. No endangered species exist at the Plant, and no population-level effects due to plutonium were found.

Based on an analysis of potential public health impacts, it is concluded that there is no immediate public health threat. This is because neither surface water nor air are contaminated by the SWMUs and because a travel time on the order of 80 years has been predicted for ground-water transport of dissolved chemical species to the property boundary in the valley fill alluvium. However, a risk assessment (Rockwell, 1988) indicates that the potential for future exposure via the ground-water pathway may pose an unacceptable risk to the public, and a feasibility study has been undertaken to select an appropriate remedial action.

Section 2.0

2.0 INTRODUCTION

A comprehensive, phased program of site characterization, remedial investigations, feasibility studies, and remedial/corrective actions is in progress at the Rocky Flats Plant. These investigations are pursuant to the U.S. Department of Energy (DOE) Comprehensive Environmental Assessment and Response Program (CEARP) and a Compliance Agreement finalized by representatives of DOE, the U.S. Environmental Protection Agency (EPA) and the State of Colorado (CDH) on July 31, 1986. The Agreement addresses hazardous and radioactive mixed waste management at the Rocky Flats Plant. The program developed by DOE, EPA, and CDH in response to the Agreement addresses RCRA and CERCLA issues and has been integrated with CEARP investigations.

CEARP is being implemented in five phases. CEARP Phase 1 (Installation Assessment) has already been completed at Rocky Flats Plant. CEARP Phase 1 evaluated compliance with environmental laws and ascertained the magnitude of potential environmental concerns. CEARP Phase 2 (Monitoring Plans and Remedial Investigations) will complete the evaluation of potential environmental concerns identified in CEARP Phase 1. It will also plan and implement sampling programs to understand potential contaminant sources and environmental pathways. This report presents results of CEARP Phase 2 remedial investigations for the high priority sites at Rocky Flats Plant. CEARP Phase 3 (Feasibility Studies) will evaluate remedial alternatives and develop remedial action plans to mitigate environmental problems identified as needing correction in CEARP Phase 2. CEARP Phase 4 (Remedial/Corrective Action) will design and implement the site-specific remedial actions selected on the basis of CEARP Phase 3 feasibility studies. CEARP Phase 5 (Compliance and Verification) will implement monitoring and performance assessment of remedial action and will verify and document the adequacy of remedial actions carried out under CEARP Phase 4.

CEARP Phase 2 consists of CEARP Phase 2a, Monitoring Plans, and CEARP Phase 2b, Remedial Investigations. CEARP uses a three-tiered approach in preparing monitoring plans: the CEARP Generic Monitoring Plan (CGMP, DOE, 1986a), the Installation Generic Monitoring Plan (IGMP, DOE, 1987a), and Site Specific Monitoring Plans/Remedial Investigation Plans (SSMP/RI/FS). Each monitoring plan typically consists of five parts: Synopsis, Sampling Plan, Technical Data Management Plan, Health and Safety Plan, and Quality Assurance/Quality Control Plan.

Installation and site specific monitoring plans were submitted to EPA and CDH in February 1987 (DOE, 1987a and 1987b). The IGMP is the Rocky Flats Plant Comprehensive Source and Plume Characterization Plan, and the SSMP is the Remedial Investigation (RI) Work Plan for the high-priority sites at the 881 Hillside Area and other priority sites including the 903 Pad, Mound, and East Trenches Areas.

2.1 REPORT OVERVIEW

This report describes the remedial investigations performed at the high priority sites at Rocky Flats Plant. All of the high priority sites at Rocky Flats Plant are located in the 881 Hillside Area. Presented are interpretations and conclusions from the remedial investigation and an assessment of public health and environmental concerns. The report format follows EPA guidance for remedial investigations (EPA, 1985b).

The report begins with site background information. Presented in this introduction are site locations and descriptions, results of previous investigations, the nature and extent of problems at these sites, objectives of this remedial investigation, and a description of remedial investigation field activities. The introduction is followed by a regional setting chapter (Section 3.0) which describes demography, land use, climatology, physiography, soils and geology, hydrogeology, and water resources in the vicinity of Rocky Flats Plant.

Following the introduction and regional setting chapters is the waste source characterization. This chapter (Section 4.0) characterizes each site based on remedial investigation results and previous studies. The location and extent of soil contamination is also presented for each site.

After describing the waste sources, a chapter is devoted to each potential contaminant pathway. Section 5.0 discusses the site geologic setting, characterizes ground-water flow paths, and discusses the extent of ground-water contamination resulting from each site. Section 6.0 characterizes the surface water pathway. Presented are descriptions of surface water flow paths, surface water quality, sediment chemistry, and flood potential. Section 7.0 characterizes the air pathway based on sampling results, and Section 8.0 describes site biota. The remedial investigation report concludes by addressing public health and environmental concerns (Section 9.0).

Appendices A through I contain remedial investigation supporting data. Excerpts from the RI Sampling Plan pertaining to the 881 Hillside Area are presented in Appendix A, and Appendices B and C contain results of geophysical and soil gas surveys, respectively. Appendix D presents a description of and rationale for the remedial investigation drilling program. Drilling, soil sampling, and ground-water sampling procedures are also discussed in Appendix D. Resulting hydrogeologic and analytical data are presented in Appendices E and F, respectively. Appendix G contains quality assurance/quality control (QA/QC) documentation for field and laboratory activities. Appendix H contains biota information, and Appendix I contains air quality data.

2.2 SITE LOCATIONS AND DESCRIPTIONS

The Rocky Flats Plant is located in northern Jefferson County, Colorado, approximately 16 miles northwest of Denver (Figure 2-1). The Plant consists of approximately 6,550 acres of federally owned land in Sections 1 through 4 and 9 through 15 of T2S, R70W, 6th principal meridian. Major buildings are located within the Plant security area of approximately 400 acres. The security area is surrounded by a buffer zone of approximately 6,150 acres (Figure 2-2).

This remedial investigation report addresses the 881 Hillside Area located on the south side of the Rocky Flats Plant security area. These sites were designated high priority sites because of their suspected relationship to ground-water contamination (DOE, 1987b). Several sites are included in the 881 Hillside Area because of their physical proximity to each other. Figure 2-3 shows the location of the 881 Hillside Area and presents the site locations within the area.

A complete list of solid waste management units at the Plant is presented in Appendix 1 of the RCRA Part B Operating Permit Application (Rockwell International-

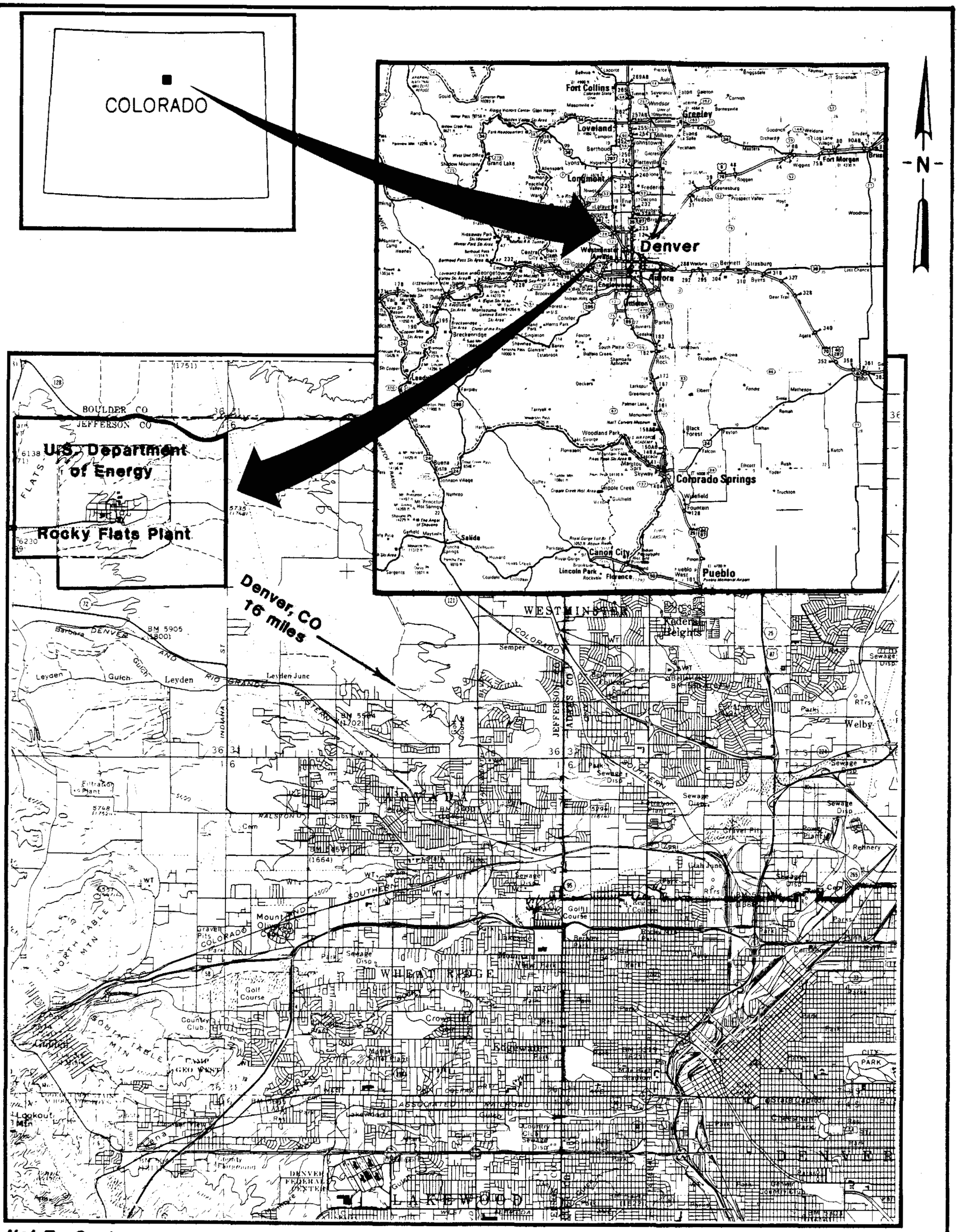

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Figure 2-1: Location of Rocky Flats Plant

al, 1986a). These solid waste management units are divided into three categories. The first category includes those hazardous waste management units which will continue to operate and require a RCRA operating permit. The second category includes those hazardous waste management units that are being closed under RCRA interim status regulations and require a Post Closure Care Permit. The third category includes those inactive waste management units that are identified under Section 3004(u) of RCRA and CERCLA. Another class of sites is regulated only under CERCLA. These CERCLA sites contain only radioactive wastes. For ease in referencing these units and sites, and in accordance with RCRA terminology, each site is designated a Solid Waste Management Unit (SWMU) and assigned a reference number. No distinction is made in this report between RCRA and CERCLA sites. A base map and a tabulation of all SWMUs cross-referenced to the CEARP Phase 1 report is contained within the IGMP Monitoring Plan for Rocky Flats Plant (DOE, 1987a).

The site descriptions presented in the Introduction are taken from the Rocky Flats Plant CEARP Phase I Report (DOE, 1986b), the RCRA Part B Operating Permit Application (Rockwell International, 1986a), and results of this investigation. These descriptions are based on historical records, aerial photography review, and interviews with Plant personnel. Further characterization of each site based on this remedial investigation is presented in Chapter 4, "Waste Source Characterization", and revised SWMU locations are shown on Plate 4-1.

2.2.1 881 Hillside Area

Twelve sites are located within the 881 Hillside Area. These sites are:

- Oil Sludge Pit Site (SWMU Ref. No. 102);
- Chemical Burial Site (SWMU Ref. No. 103);
- Liquid Dumping Site (SWMU Ref. No. 104);

- Out-of-Service Fuel Tanks Sites (SWMU Ref. Nos. 105.1 and 105.2);
- Outfall Site (SWMU Ref. No. 106);
- Hillside Oil Leak Site (SWMU Ref. No. 107);
- Multiple Solvent Spills Sites (SWMU Ref Nos. 119.1 and 119.2);
- Radioactive Site--800 Area Site #1 (SWMU Ref. No. 130);
- Sanitary Waste Line Leak Site (SWMU Ref. No. 145); and
- Building 885 Drum Storage Area (SWMU Ref. No. 177).

Presented below are descriptions of each of these sites.

Oil Sludge Pit Site (SWMU Ref. No. 102)

Approximately 30 to 50 drums of oil sludge were emptied into a pit south of Building 881 in the mid-1950s. The sludge was collected during cleaning of the two No. 6 fuel oil tanks south of Building 881 (SWMUs 105.1 and 105.2). The pit was located approximately 180 feet south of the southeast corner of Building 881 and had dimensions approximately 50 by 80 feet (Rockwell International, 1986a). The oil sludge pit site was identified on 1955 aerial photographs and was covered with fill after its use based on 1963 aerial photographs.

Chemical Burial Site (SWMU Ref. No. 103)

An area south of Building 881 was reportedly used to bury unknown chemicals (DOE, 1986b). The exact location, dates of use, and contents of the site are unknown. Prior to this investigation, the site was thought to be located in the same area as the Oil Sludge Pit Site (Rockwell International, 1986a). The location of this unit has been revised based on this investigation (Section 4.0).

Liquid Dumping Site (SWMU Ref. No. 104)

An area east of Building 881 was reportedly used for dumping unknown liquids and for disposing of empty drums prior to 1969 (DOE, 1986b). A pit was reported with plan dimensions of approximately 50 by 50 feet based on 1965 aerial photographs (Rockwell International, 1986a). Further analysis of the air photos during this investigation did not confirm the preliminary identification made in 1986 (Section 4.0).

Out-of-Service Fuel Tanks Sites (SWMU Ref. Nos. 105.1 and 105.2)

Asbestos was placed in two out-of-service no. 6 fuel tanks located south of Building 881, and the tanks were later filled with concrete (DOE, 1986b). The exact dates of these activities are unknown; however, they apparently occurred subsequent to use of the fuel oil storage tanks (after 1976) (Rockwell International, 1986a).

Outfall Site (SWMU Ref. No. 106)

A six-inch diameter vitrified clay pipe outfall existed south of Building 881. This pipe discharged water in 1977. Previous reports indicated that this was a cleanout pipe for an overflow line from the Building 881 cooling tower (Rockwell International, 1986a). However, construction drawings reviewed during this investigation indicate that the pipe is an overflow sewer line from Building 887 (Section 4.0).

Hillside Oil Leak Site (SWMU Ref. No. 107)

An oil leak was discovered on the hillside south of Building 881 in May 1973. The oil was believed to be from the fuel oil storage tanks south of Building 881 (SWMUs 105.1 and 105.2); however, leak tests on the tanks and associated lines did not show any leakage. The oil spill was contained with straw, and the straw and soil were removed and disposed of in the present landfill north of the Plant (Rockwell International, 1986a).

Prior to 1975, oil had emerged through the Building 881 footing drain outfall. A ditch and skimmer pond were built to contain the oil. These structures are still present, although no oil has been observed in the outfall since 1973 (Rockwell International, 1986a). SWMU 107 includes the Building 881 footing drain and skimmer pond.

Multiple Solvent Spill Sites (SWMU Ref. Nos. 119.1 and 119.2)

Beginning in 1967, two areas east of Building 881 and along the southern perimeter road were used as solvent storage facilities. The two areas were expanded from 1967 to 1971, and major expansion of the western area (SWMU 119.1) occurred in 1969. Both storage facilities were removed by 1972. The exact types and quantities of solvents stored at this facility are unknown (Rockwell International, 1986a).

Radioactive Site--800 Area Site #1 (SWMU Ref. No. 130)

An area east of Building 881 and northwest of SWMU 119.1 was used from 1969 to 1972 to dispose of up to 400 tons of plutonium contaminated soil. These materials were derived from cleanup of the area around Building 776 after the 1969 fire and from Central Avenue between 8th and 10th Streets. The average plutonium activity of the material from the fire cleanup was estimated to be seven disintegrations per minute per gram (dpm/g) (Rockwell International, 1986a).

Sanitary Waste Line Leak Site (SWMU Ref. No. 145)

A four-inch cement-asbestos sanitary waste line located south of Building 881 leaked in January 1981. An earthen dike was constructed to prevent the spill from entering the South Interceptor Ditch, and the line was repaired. The presence of hazardous materials in this line is unknown (Rockwell International, 1986a). Review of Building 881 construction drawings does not indicate any four-inch cement-asbestos sanitary waste lines south of the building.

Building 885 Drum Storage Area (SWMU Ref. No. 177)

The Building 885 Drum Storage Area will be closed under RCRA Interim Status (6 CCR 1007-3). Complete information on this unit is provided in the RCRA Closure Plan.

2.3 PREVIOUS INVESTIGATIONS

A series of investigations has been conducted at the Plant to characterize ground water, surface water, soils, air quality, and biota. A summary of investigations performed prior to 1987 remedial investigations is provided in the RCRA Part B Operating Permit Application (Rockwell International, 1986a). These programs include:

1) Several drilling programs beginning in 1961 that resulted in approximately 60 monitor wells by 1985;

2) An investigation of surface and ground water by the U.S. Geological Survey (Hurr, 1976);

3) Environmental, ecological, and public health studies which culminated in an Environmental Impact Statement (DOE, 1980);

4) An integrative report on ground-water hydrology using data from 1961 to 1985 (Hydro-Search, Inc., 1985);

5) A preliminary electromagnetic survey of the Plant perimeter (Hydro-Search, Inc., 1986);

6) A soil gas survey of the Plant perimeter and buffer zone (Tracer Research, Inc., 1986);

7) A review of historical waste disposal practices and prioritization of disposal sites based on reported waste disposal practices and on ground-water quality, geophysical, and soil gas data (Rockwell International, 1986b and DOE, 1986b);

8) An initial site characterization including surface water monitoring and sampling, sediment sampling, and installation of 69 new monitor wells at the Plant (Rockwell International, 1986a, 1986d, and 1986e);

9) A remedial investigation of the 903 Pad, Mound, and East Trenches Areas performed in 1987 (Rockwell International, 1987b); and

10) Environmental monitoring programs addressing air, surface water, ground water, and soils (Rockwell International, 1975-1985, 1986g, and 1987a).

Although none of the above investigations was specific to the 881 Hillside Area, several monitor wells have been installed in the area as part of Plant-wide investigations. Surface water, soil, and air samples have also been collected in the vicinity of the 881 Hillside Area as part of various investigations. Presented below is a summary of previous investigations and a brief characterization of each pathway at the 881 Hillside Area. Impacts to these pathways from the area as perceived prior to this RI are discussed in Section 2.4.

2.3.1 Ground-Water Pathway

Geologic information was collected prior to Plant construction in the early 1950s, and the ground-water pathway has been monitored since 1960. The initial site characterization performed in 1986 involved the installation of 69 new wells to monitor both alluvial and bedrock ground-water quality. This work, coupled with earlier investigations (Hurr, 1976; Hydro-Search, Inc., 1985), has characterized the Plant-wide hydrogeology and the site-specific hydrogeology of the solar evaporation ponds. The results of the initial site characterization are presented in Rockwell International (1986a) and summarized in the RI Work Plan (DOE, 1987b). Additional ground-water pathway information was collected as outlined in the Work Plan (DOE, 1987b). Plate 2-1 shows all monitor well locations at Rocky Flats Plant.

Ground water occurs in both surficial and bedrock materials at the 881 Hillside Area. The major source of recharge is infiltration of incident precipitation into surficial materials, although seepage from ditches also contributes to recharge. Most of the infiltrated water flows in surficial materials toward the drainages on top of the low permeability Arapahoe Formation claystones.

Some of the water in the Rocky Flats Alluvium emerges as seeps and springs at the contact between the alluvium and bedrock (contact seeps), most of which is consumed by evapotranspiration. In addition, some of the water is carried in the colluvium to the valley fill alluvium, where it either flows down-valley in the alluvium, is consumed by evapotranspiration, or discharges to streams. During the driest periods of the year, evapotranspiration dominates the shallow flow system, and there is no flow in some areas of the colluvium and valley fill alluvium.

Ground water in the surficial materials also enters the bedrock flow system by leakage through the claystones to the sandstones (very small quantity flows) or by direct recharge to sandstone units where sandstones subcrop beneath the soils. Water in the Arapahoe Formation flows generally to the east at a gradient of about 0.03 (Hurr, 1976).

2.3.2 Surface Water Pathway

The surface water pathway at Rocky Flats Plant has been characterized by Hurr (1976) and Rockwell International (1986h). Considerable work has also been done characterizing surface water and sediment chemistry in downstream reservoirs. Surface water and sediment data were collected during the initial site characterization at Rocky Flats Plant (Rockwell International, 1986a). Additional site-specific surface water information was collected as part of this remedial investigation. This section describes surface water flow at the Plant and in the vicinity of the 881 Hillside. Included is a description of natural drainages, ponds, ditches, and diversions.

Three intermittent streams drain the Rocky Flats Plant site with flow generally from west to east (Figure 2-2). Rock Creek drains the northwestern corner and flows to the northeast in the buffer zone to its off-site confluence with Coal Creek. Woman Creek drains the southern portion of the Plant and flows eastward to Standley Lake and Mower Reservoir. Surface water flow to the south from the 881 Hillside Area is received by the South Interceptor Ditch and routed to pond C-2, which is isolated from Woman Creek. North and South Walnut Creeks and an unnamed tributary drain the remainder of the Plant. The three forks of Walnut Creek join in the buffer zone (approximately 0.7 miles downstream of the eastern edge of the Plant security area) and flow to Great Western Reservoir approximately one mile east of the confluence of the forks.

A series of dams, retention ponds, diversion structures, and ditches has been constructed at the Plant to control surface water and limit the potential for release of poor quality water. These structures and flow systems are described briefly below.

A series of retention ponds is located in the drainages of Walnut and Woman Creeks. The ponds are designated as the A, B, and C series ponds. Discharges from the downstream pond in each series are in accordance with the Plant's National Pollution Discharge Elimination System (NPDES) permit. Ponds A-1 and A-2 are used only for spill control, and North Walnut Creek stream flow is diverted around them through an underground pipe. Pond A-3 receives the North Walnut Creek stream flow and Plant runoff from the northern portion of the Plant. Pond A-4 is designed for surface water control and for additional storage capacity for overflow from pond A-3. None of the 881 Hillside remedial investigation sites drain into North Walnut Creek.

Five retention ponds are located along South Walnut Creek and are designated as B-1, B-2, B-3, B-4, and B-5, from west to east. Ponds B-1 and B-2 are reserved for spill control, whereas pond B-3 receives effluent from the sanitary sewage treatment plant. Ponds B-4 and B-5 receive surface runoff and occasionally collect discharge from pond B-3. Pond B-5 receives runoff from the central portion of the Plant site and is used for surface water control in addition to collection of overflow from pond B-4. None of the 881 Hillside remedial investigation sites drain into South Walnut Creek.

The two C series ponds, C-1 and C-2, are located along Woman Creek, south and east of the Plant, respectively. Pond C-1 receives stream flow from Woman Creek. This flow is diverted around pond C-2 into the Woman Creek channel downstream. Pond C-2 is isolated from Woman Creek and receives surface runoff from the South Interceptor Ditch along the southern portion of the Plant site. Water in pond C-2 is discharged to Woman Creek in accordance with the Plant NPDES permit.

There are many runoff control ditches in the general vicinity of the Plant. The largest of these is the Central Avenue Ditch which runs eastward along Central Avenue and discharges to South Walnut Creek (Pond B-5). The Central Avenue Ditch crosses the center of the Mound Area and the northern portion of the East Trenches Area. The other major runoff control ditch is the South Interceptor Ditch which isolates runoff from the south side of the Plant from Woman Creek. Surface water runoff from the 881 Hillside and 903 Pad Areas flows south to the South Interceptor Ditch. The ditch extends from the old landfill to pond C-2, and Woman Creek is diverted around pond C-2 by a diversion structure just upstream of the pond.

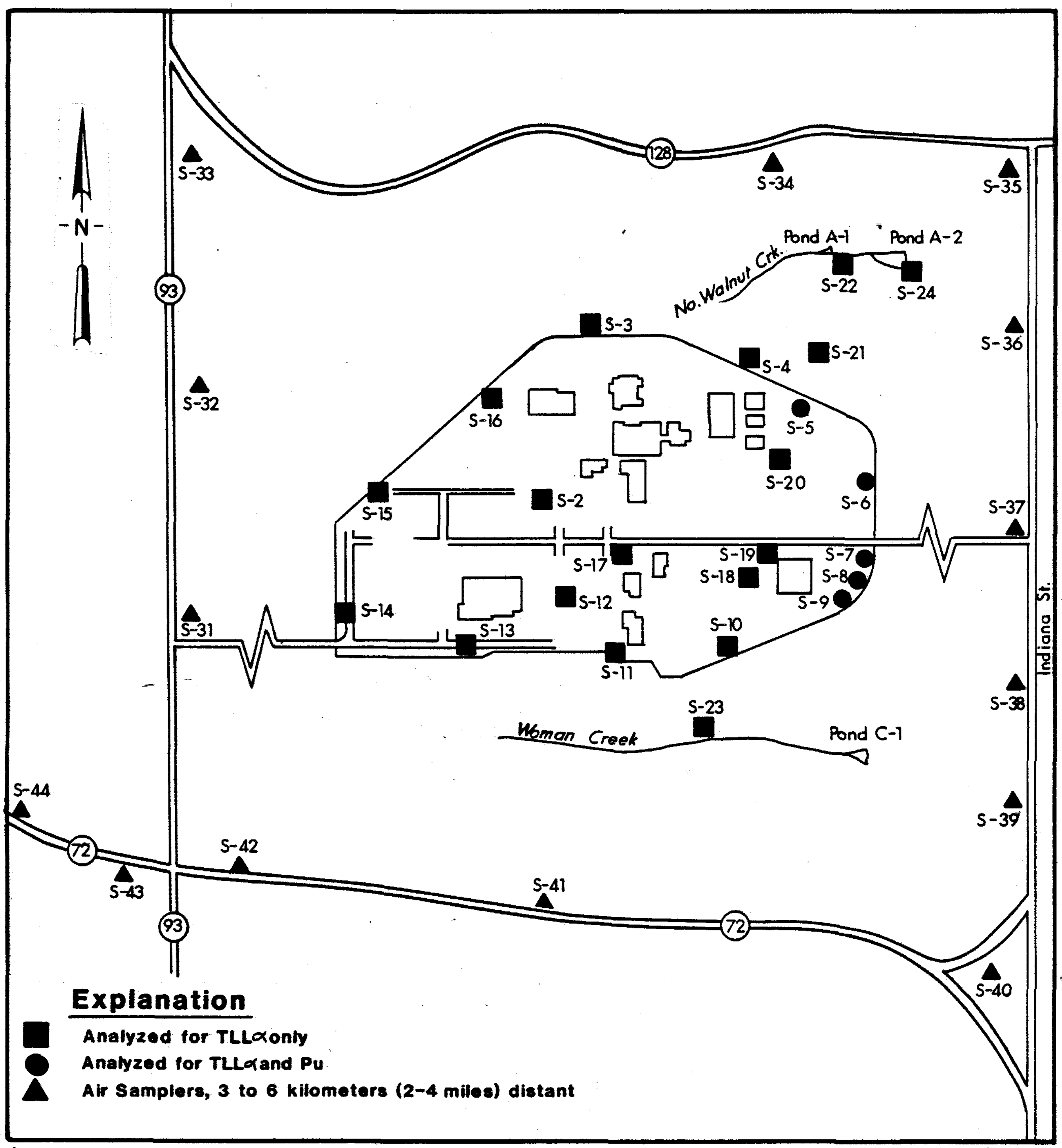
2.3.3 Air Pathway

Air pathway studies at Rocky Flats Plant are performed continuously and reported annually in Annual Environmental Monitoring Reports (Rockwell International, 1975-1985, 1986g, and 1987a). In addition, the air pathway was further characterized by Rockwell International (1986f) in the "Rocky Flats Plant Radioecology and Airborne Pathway Summary Report".

Air samplers for routine ambient air monitoring at the Plant are located at various locations on and off Plant site. This ambient air program monitors only radionuclides. Conventional air quality parameters are monitored on site at a dedicated location inside the perimeter security fence west of the East Guard Gate.

The Plant Radioactive Ambient Air Monitoring Program (RAAMP) is comprised of 51 high-volume particulate air samplers which operate continuously. Twenty-three (23) of the 51 air samplers are within or directly adjacent to the Plant security area (on-site samplers), and 14 are located around the Plant property boundary (perimeter samplers) (Figure 2-4). An additional 14 samplers (community samplers) are located in neighboring towns (Figure 2-5).

Data collected at Rocky Flats Plant indicate a low potential for significant human exposure to radioactive and nonradioactive airborne emissions from the Plant. All perimeter and community ambient air samplers have recorded mean annual plutonium concentrations at less than 0.4% of the Derived Concentration Guide (DCG), which is based on the DOE interim standard dose limit for all pathways of 0.1 rem/yr for a 50-year committed effective dose equivalent (Rockwell International, 1986g). This level is indistinguishable from fallout.



(after: Rockwell International, 1984)

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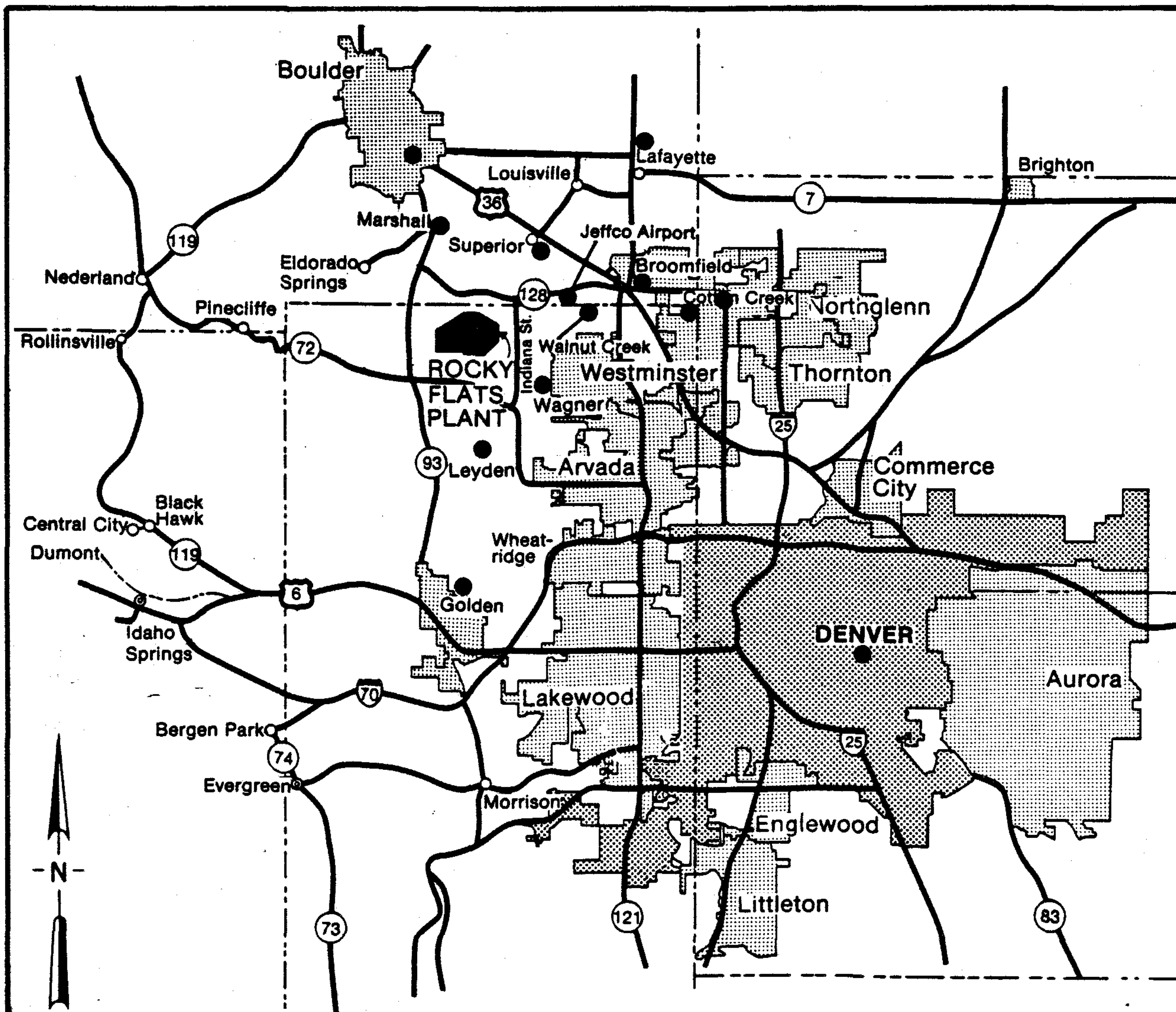
Figure 2-4:
Location of On-Site and Plant Perimeter Ambient Air Samplers



Explanation

● Off-Site Community Ambient Air Samplers

(after: Rockwell International, 1984)

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Figure 2-5:
Location of Off-Site Community Ambient Air Samplers

Volatile organic compounds were not detected in the ambient air during this investigation using photoionization detectors at 881 Hillside sites suspected to contain high concentrations of volatile solvents.

2.4 NATURE AND EXTENT OF THE PROBLEM

The CEARP Phase 1 Installation Assessment for Rocky Flats Plant (DOE, 1986b) included analyses of current operational activities, active and inactive waste sites, current and past waste management practices, and potential environmental pathways through which contaminants could be transported.

Potential contaminant source areas were evaluated and prioritized based on preliminary investigations (DOE, 1986b; Rockwell International, 1986a and 1986b). Four areas are currently under investigation using the RI approach detailed in DOE (1987a and 1987b). These areas are:

1) 881 Hillside Area,
2) 903 Pad Area,
3) Mound Area, and
4) East Trenches Area.

This report presents results of remedial investigations at the 881 Hillside Area. Preliminary remedial investigation results from the 903 Pad, Mound, and East Trenches Areas are presented in Rockwell International (1987b).

881 Hillside Area

Based on previous investigations, the principal chemical contaminants of concern at the 881 Hillside Area are tetrachloroethene (PCE), trichloroethene (TCE), 1,1,1-trichloroethane (TCA), and 1,1-dichloroethene (DCE) in ground water (Rockwell

International, 1986a). Prior to this remedial investigation, the highest measured concentrations of these compounds occurred in well 9-74 in 1986, with lower concentrations occurring in previous sampling events. The highest values were 4800 parts per billion (ppb) of PCE, 11,000 ppb of TCE, 14,000 ppb of TCA, and 7,200 ppb of DCE (Rockwell International, 1986a).

Wells 64-86 and 65-86 monitor alluvial water quality in the Woman Creek valley fill materials downgradient of the 881 Hillside Area. Volatile organics have not been detected in either of these wells, and radionuclides were within background levels in 1986 indicating that contaminants present at the 881 Hillside have not migrated as far as Woman Creek (Rockwell International, 1986a).

2.5 REMEDIAL INVESTIGATION SUMMARY

2.5.1 Objectives

The objectives of this remedial investigation were to:

1) Verify waste source locations;
2) Characterize waste sources;
3) Characterize site geology and hydrology;
4) Determine the presence and extent of ground-water, surface water, soils, air, and biota contamination;
5) Provide data to estimate the potential for contaminant migration via the ground-water, surface water, and air pathways; and
6) Support feasibility studies of alternative remedial actions.

2.5.2 Field Investigation Summary

Field investigations were performed in two phases at the 881 Hillside Area to meet the objectives listed above. The first phase of investigations began in March 1987, following the plans presented in DOE (1987a and 1987b). The second phase of field work was performed subsequent to submittal of the draft 881 Hillside Area RI Report and meetings with CDH and EPA to plan further work based on Phase I results. Excerpts from the RI Sampling Plan, outlining sampling locations and rationale for the field program, are presented in Appendix A. Drilling and sampling procedures followed during the RI are presented in the IGMP/CSPCP Sampling Plan (DOE, 1987a). Appendix D discusses actual drilling locations and rationale as well as any deviations from the RI Work Plan or IGMP/CSPCP Sampling Plans.

The field program consisted of:

1) Preparation of detailed topographic site maps;
2) Radiometric and organic vapor screening surveys (Section 7.0);
3) Geophysical surveys using electromagnetometry, resistivity, magnetometry, and metal detection (Appendix B);
4) Soil gas sampling (Appendix C);
5) Drilling, sampling, and analyses of subsurface soils from 17 Phase I boreholes and six Phase II boreholes (Section 4.0 and Appendices D, E, and F);
6) Installation of 4 alluvial wells and 3 bedrock wells during Phase I drilling and 11 alluvial wells and 1 bedrock well during Phase II drilling (Section 5.0 and Appendices D, E, and F);
7) Packer testing of cored bedrock wells (Appendix E);
8) Slug testing on all new wells containing sufficient water for testing (Appendix E);

9) Sampling and analysis of ground water from all 1986 wells (up to five quarters of data) and 1987 wells (in general, two samples for Phase I wells and one sample for Phase II wells) in the study area in addition to older wells which had shown contamination in the past (Section 5.0 and Appendices D, E, and F);

10) Surface water sampling and analysis from stations along Woman Creek and the South Interceptor Ditch, as well as from seeps and springs located in the area (Section 6.0); and

11) Sediment sampling analysis in Woman Creek (Section 6.0).

Section 3.0

3.0 REGIONAL SETTING AND SITE FEATURES

This section presents the regional setting of Rocky Flats Plant and the 881 Hillside Area. Included are sections on demography, land use, natural resources, climatology, and water resources in the vicinity of Rocky Flats Plant. Also presented is a section on soils, geology, and hydrogeology. This section is divided into a discussion of regional (Denver Basin) geology and local Rocky Flats geology. Site specific discussions of geology and hydrogeology at the 881 Hillside Area are presented in Section 5.0.

3.1 DEMOGRAPHY

Rocky Flats Plant is located in northern Jefferson County, Colorado; approximately 50 percent of the area within ten miles of the Plant is within Jefferson County. The remainder of the area within ten miles of the Plant is located in Boulder County (40 percent) and Adams County (10 percent). According to the 1973 Colorado Land Use Map, 75 percent of this land was unused or was used for agriculture. Since that time portions of this land have been converted to housing, and several new housing subdivisions are located within a few miles of the Plant. One subdivision is located south of the Jefferson County Airport, and several are located southeast of the Plant.

A demographic study using 1980 census data (Rockwell International, 1985) shows that approximately 1.8 million people lived within 50 miles of the Plant in 1980. This was projected to increase to 3.5 million people by the year 2000. Approximately 9,500 people lived within 5 miles of the Plant in 1980, with a route for employees. The junction of Highway 17 and Colorado 72 southeast of the Plant carried about 3,800 cars daily during 1978. The D&RGW Railroad, which is about two miles south of the Plant, is the main line west from Denver. Several trains a day use this line to haul freight, coal, and passengers (DOE, 1980). A spur of the D&RGW rail line enters the Plant from the southwest.

Some of the land adjacent to the Plant is zoned for industrial development. Industrial facilities within five miles of the Plant include the TOSCO laboratory (40 acre site located two miles south), the Great Western Inorganics plant (two miles south), the Frontier Forest Products yard (two miles south), the Idealite lightweight aggregate plant (2.4 miles northwest), and the Jeffco Airport and Industrial Park (990 acre site located 4.8 miles northeast).

Several ranches are located within ten miles of the Plant, primarily in Jefferson and Boulder Counties. They produce crops, raise beef cattle, supply milk, and breed and train horses. According to 1977 Colorado Agricultural Statistics, 14,000 acres of crops were planted in 1976 in Jefferson County (total land area of approximately 475,000 acres), and 56,200 acres of crops were planted in Boulder County (total land area of 405,760 acres). Crops consisted of winter wheat, corn, barley, dry beans, sugar beets, hay, and oats. Livestock consisted of 9,500 head of cattle, 200 pigs, and 400 sheep in Jefferson County and 34,000 head of cattle, 2,300 pigs, and 6,500 sheep in Boulder County in 1976 (DOE, 1980).

The closest park and recreational area is the Standley Lake area, which is approximately five miles east of the Plant. Boating, picnicking, and limited overnight camping are permitted. Several other small parks are present in communities within ten miles of the Plant. The closest major park is Golden Gate Canyon State Park located approximately 15 miles to the southwest. This park provides 8,400 acres of general camping and outdoor recreation. Other national and state parks are located in the mountains west of the Plant, but all are more than fifteen miles away.

3.3 NATURAL RESOURCES

Rocky Flats Plant is located along the southwest trending Colorado Mineral Belt that extends from the northeastern plains, across the central Front Range, and into the southwest mountains of Colorado. Mineral resources in the vicinity of the Plant include sand and gravel, crushed rock, clay, coal, and uranium (Van Horn, 1972). Oil and natural gas resources are also present to the north and east of the Plant in Boulder, Weld, and Adams Counties. Several mining and quarry operations are also currently active or have been active in the past; these activities are described below.

3.3.1 Aggregate Resources

Extensive deposits of sand and gravel from the Rocky Flats Alluvium are a source of aggregate at the Plant which is suitable for concrete and mineral aggregate. There are currently sand and gravel pits operating about one mile southwest and approximately one-half mile west of the Plant. Several quarries have extracted rock from the Precambrian metamorphics and the Tertiary igneous rock exposed in the Golden Quadrangle for use as concrete aggregate, riprap, and road material. Rock is presently being quarried from the Ralston Dike about four miles southwest of the Plant.

Clay mined from the Laramie Formation and the Pierre Shale (west of the Plant) from Coal Creek south to Golden is used for brick, tile, and sewer pipe. Three pits in clay and claystone beds of the steeply dipping lower part of the Laramie Formation are presently being mined. Clay from the upper part of the Pierre Shale was mined and treated to form a lightweight aggregate at the facility operated by the Idealite Cement Company near the northwest corner of the Plant. The Idealite operation closed in 1976 (DOE, 1980).

3.3.2 Coal Resources

Sub-bituminous coal occurs in several lenticular bodies in the lower part of the Laramie Formation. This coal has been mined in the Golden Quadrangle south of the Plant and from the Louisville Quadrangle north of the Plant. No mining has occurred since 1950, and few sizeable areas remain where coal is of sufficient thickness and quality to justify mining (Spencer, 1961).

3.3.3 Uranium Resources

Uranium has been mined at the Schwartzwalder uranium mine about four miles southwest of the Plant. The mine has been the largest producer of vein-type uranium ore in Colorado and ranks among the six largest of this type in the United States. Ore shipments have yielded more than 11.5 million pounds of uranium (DOE, 1980).

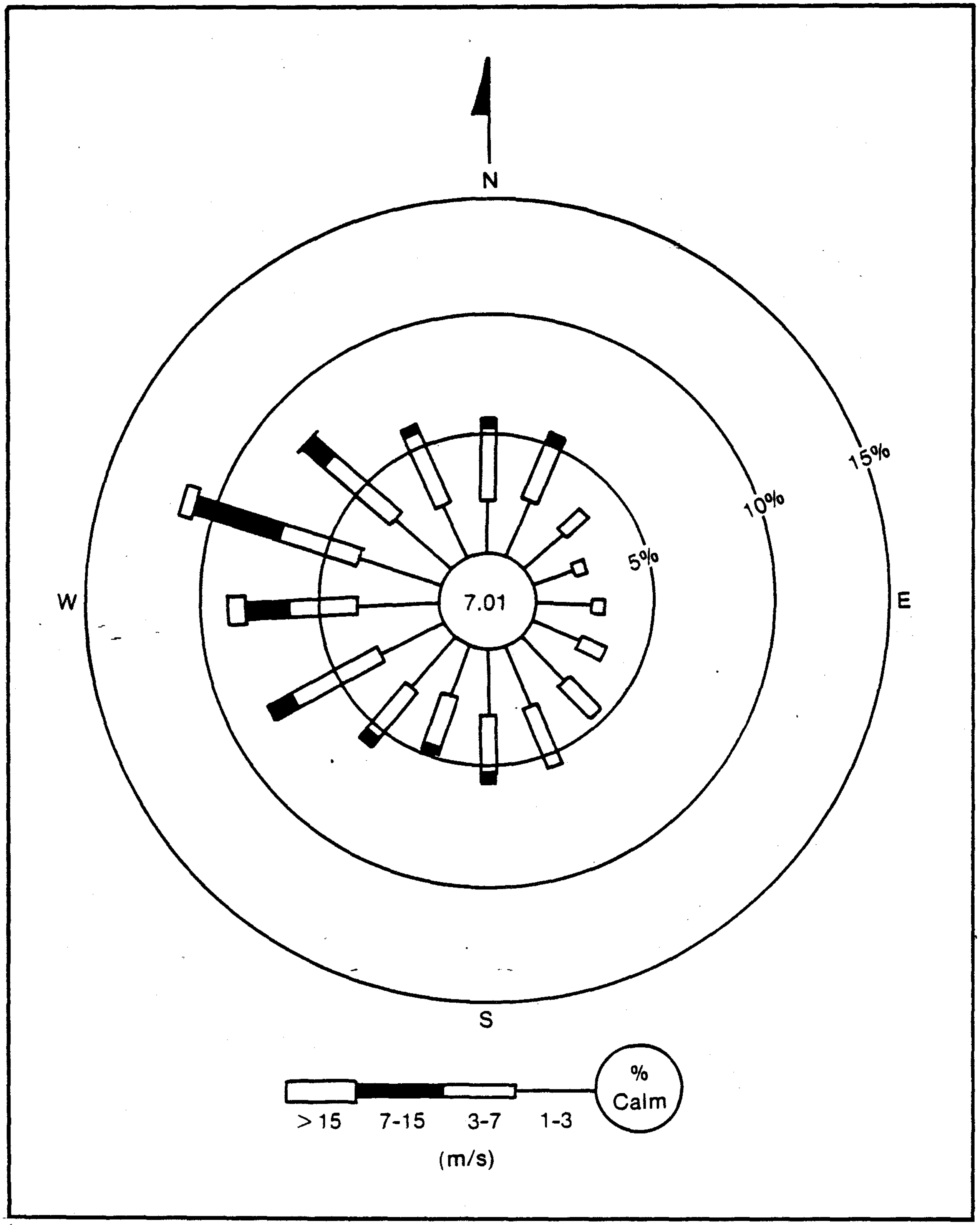
3.3.4 Oil and Gas Resources

Oil and natural gas activity near Rocky Flats Plant includes oil field developments, pipeline, and production operations. The closest major oil and gas fields are in northwest Adams County (Jackpot and Spindle Fields), and a smaller field occurs in east central Boulder County (Boulder Field). A natural gas pipeline that originates in Wyoming and proceeds across eastern Colorado into Oklahoma is located approximately ten miles north of the Plant in southern Boulder County. Local natural gas pipelines cross the south side of the Rocky Flats Plant. The nearest refinery operation is the Conoco Refinery located in Commerce City about 20 miles east of the Plant. A north-south oriented oil pipeline feeds into the refinery from fields in northeastern Colorado and southeastern Wyoming (Donaldson and MacMillan, 1980).

3.4 CLIMATOLOGY

The area surrounding the Rocky Flats Plant has a semiarid climate typical of the Rocky Mountain region. However, the elevation of the Plant and the nearby slopes of the Front Range slightly modify the regional climate.

Winds at Rocky Flats Plant, although variable, are predominantly westerly and northwesterly. Stronger winds occur during the winter, and the area occasionally experiences Chinook winds with gusts up to 100 miles per hour because of its location near the Front Range (DOE, 1980). Figure 3-2 shows the wind direction, frequency, and average velocity for each direction as recorded in 1985.



(after: Rockwell International, 1987a)

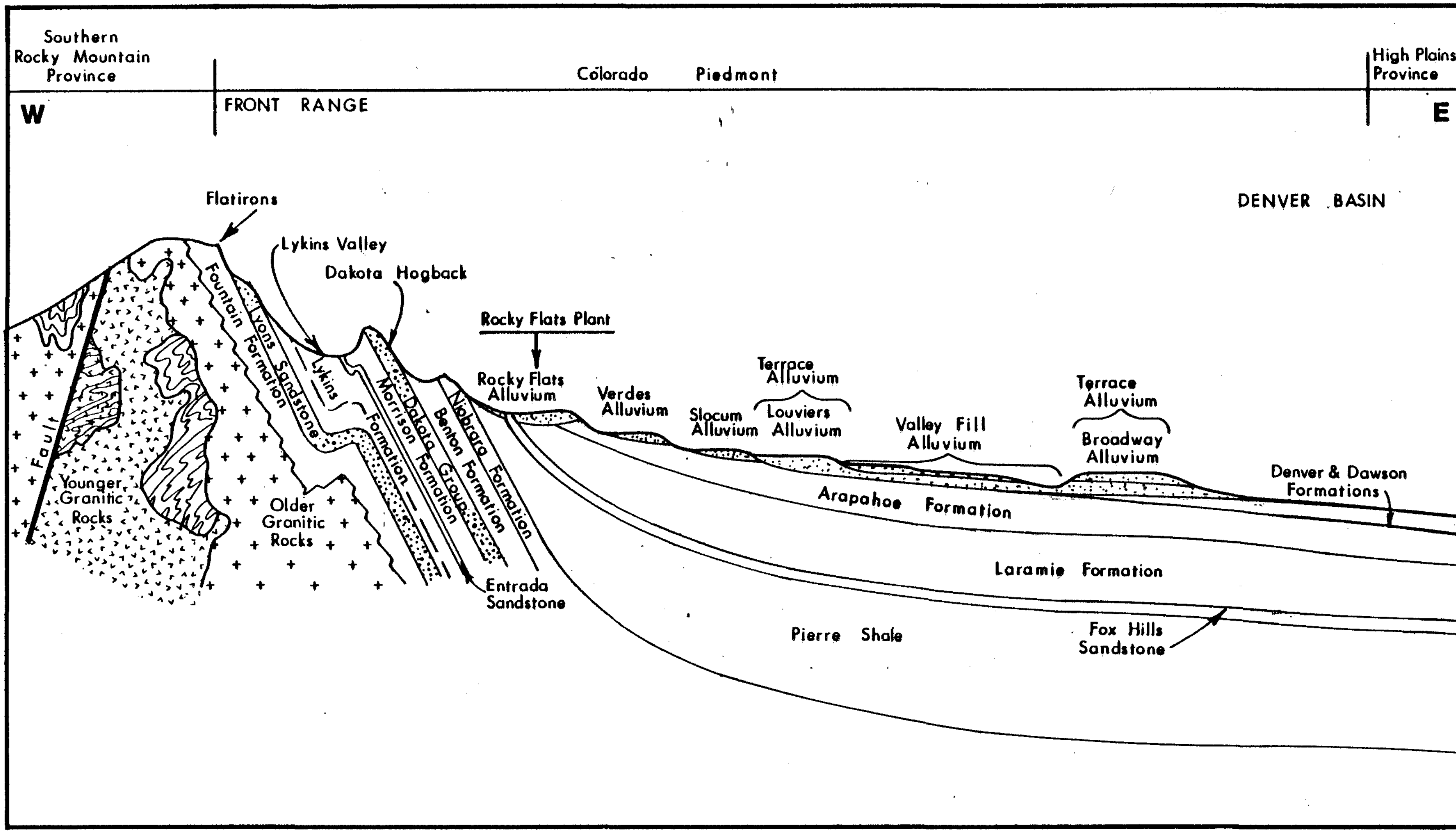
Figure 3-2:
1986 Annual Wind Rose for the Rocky Flats Plant

Temperatures are moderate; extremely warm or cold weather is usually of short duration. On the average, daily summer temperatures range from 55 to 85 degrees Fahrenheit (F) and winter temperatures range from 20 to 45 degrees F. Temperature extremes recorded at the Plant have ranged from 102 degrees F on July 12, 1971 to -26 degrees F on January 12, 1963. The 24-year average maximum temperature for the period 1952 to 1976 was 76 degrees F, the average minimum was 22 degrees F, and the average annual mean was 50 degrees F. Average relative humidity was 46 percent (DOE, 1980).

Average annual precipitation at the Plant is 15 inches. Approximately 40 percent of the precipitation falls during the spring season, much of it as snow. Thunderstorms from June to August account for an additional 30 percent of precipitation. Autumn and winter are drier seasons, accounting for 19 and 11 percent of the annual precipitation, respectively. Snowfall averages 85 inches per year, generally occurring between October and May (DOE, 1980 and Rockwell International, 1986a).

3.5 PHYSIOGRAPHY

The Rocky Flats Plant is located at an elevation of approximately 6,000 feet above mean sea level. The site is on the western margin of the Colorado Piedmont section of the Great Plains Physiographic Province (Fenneman, 1931). The Colorado Piedmont ranges in elevation from 4,000 feet on the east to 7,000 feet on the west. The Piedmont merges to the east with the High Plains section of the Great Plains Province and is terminated abruptly on the west by the Front Range section of the Southern Rocky Mountain Province (Figure 3-3).



(after: Boulder County Planning Commission, 1983 and Scott, 1960)

Not To Scale

Figure 3-3:
Generalized East-West Cross Section
Front Range to Denver Basin

The Colorado Piedmont is an area of dissected topography and denudation where Tertiary strata underlying the High Plains have been almost completely removed. In a regional context, the piedmont represents an old erosional surface along the eastern margin of the Rocky Mountains. It is underlain by gently dipping sedimentary rocks (Paleozoic to Cenozoic in age), which are abruptly upturned at the Front Range to form hogback ridges parallel to the mountain front. The piedmont surface is broadly rolling and slopes gently to the east with a topographic relief of only several hundred feet. This relief is due both to resistant bedrock units that locally rise above the surrounding landscape and to the presence of incised stream valleys. Major stream valleys which transect the piedmont from west to east have their origin in the Front Range. Small local valleys have developed as tributaries to these major streams within the piedmont. In the area of the Plant, a series of Quaternary pediments have been eroded across this gently rolling surface (Fenneman, 1931 and DOE, 1980).

The eastern margin of the Front Range a few miles west of the Plant is characterized by a narrow zone of hogback ridges and flatirons formed by steeply east-dipping Mesozoic strata (such as the Dakota Sandstone and the Fountain Formation). Less resistant sedimentary units were removed by erosion (Figure 3-3). The Front Range reaches elevations of 12,000 to 14,000 feet above mean sea level 15 miles farther west. The range itself is broad and underlain by resistant gneiss, schist and granitic rocks of Precambrian age. The resistant nature of these rocks has restricted stream erosion so that deep, narrow canyons have developed in the Front Range.

Several pediments have been eroded across both hard and soft bedrock in the area of the Plant during Quaternary time (Scott, 1963). The Rocky Flats pediment is the most extensive of these, forming a broad flat surface south of Coal Creek. The broad pediments and more narrow terraces are covered by thin alluvial deposits of ancient streams draining eastward into the Great Plains. The sequence of pediments reflects repetitive physical processes associated with cyclic changes in climate. Each erosional surface and stratigraphic sequence deposited on it probably represents a single glacial cycle. The oldest and highest pediment, the Subsummit Surface (Scott, 1960), truncates the hogback ridges of the Front Range. Three successively younger pediments, veneered by alluvial gravels, extend eastward from the mountain front. Erosion of valleys into the pediments followed each depositional cycle so that, near the mountain front, stratigraphically younger geologic units occur at topographically lower elevations as narrow terrace deposits along the streams. From oldest to youngest, the three pre-Wisconsin deposits are the Rocky Flats Alluvium, the Verdos Alluvium and the Slocum Alluvium (Scott, 1965). A series of Wisconsin and post-Wisconsin terrace deposits are present at lower elevations along streams that have incised the older pediments (east of the Plant). These alluvial deposits are described in Section 3.6.5, Surficial Geology.

The Rocky Flats Plant is located on a relatively flat surface of Rocky Flats Alluvium. The pediment surface and overlying alluvium (generally 10 to 50 feet thick, although the alluvium is as much as 100 feet thick west of the Plant) have been eroded by Walnut Creek on the north and Woman Creek on the south so that terraces along these streams range in height from 50 to 150 feet. The grade of the gently eastward-sloping, dissected Rocky Flats Alluvium surface varies from 0.7 percent at the Plant to approximately 2 percent just east of the Plant.

3.6 REGIONAL HYDROGEOLOGIC SETTING

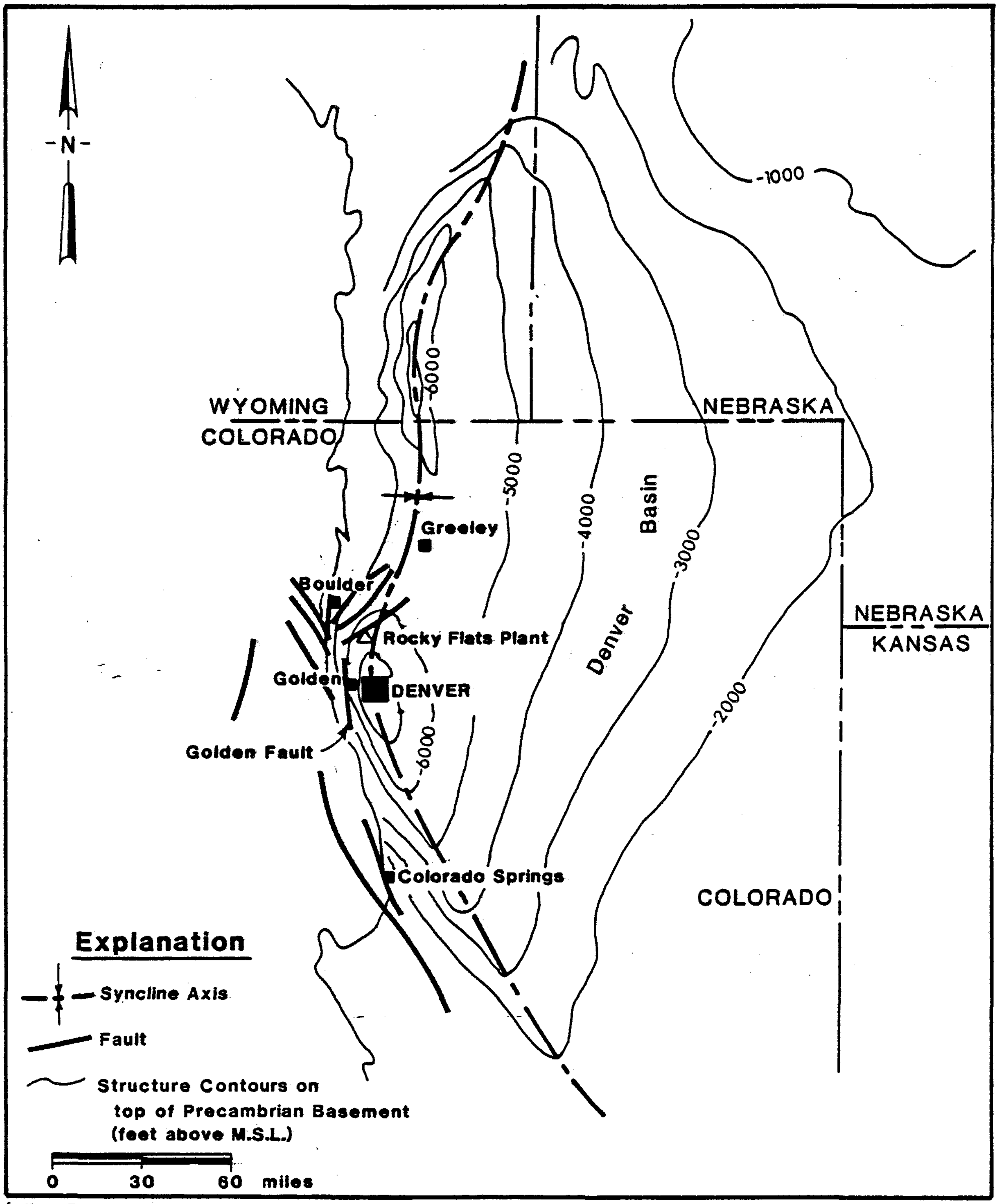
3.6.1 Geologic and Stratigraphic History

This section describes the regional geologic and stratigraphic history in the vicinity of the Plant, including the Denver Basin. Section 5.0 describes the site specific geology and stratigraphy of the Plant and study areas.

The Rocky Flats Plant is located on the northwestern flank of the Denver Basin and is underlain by about 12,000 feet of Paleozoic and Mesozoic sedimentary rocks (Hurr, 1976). The Denver Basin is an asymmetric syncline that formed during the Late Cretaceous Laramide Orogeny. The western limb of the basin dips steeply to the east, and the eastern limb dips gently to the west (Figure 3-4).

The geologic history of northeastern Colorado involves several episodes of mountain building and oceanic transgression and regression, resulting in the deposition of thousands of feet of sedimentary rock on top of the Precambrian basement. This section describes the geologic history beginning with Precambrian time. Geologic descriptions of the various units are provided within this context. More detailed descriptions of the units present on site are provided in Section 5.0.

Early Precambrian tectonic, metamorphic, and plutonic igneous activity created a complex fabric in the basement rock of Colorado (Grose, 1972). The Precambrian units were covered by marine and continental sedimentation during the lower Paleozoic (carbonate and siliciclastic rock units were deposited unconformably on the Precambrian basement). Most of these units were later eroded by multiple Paleozoic diastrophisms, thus removing Cambrian to Mississippian rocks from the



(after: Rockwell International, 1986a)

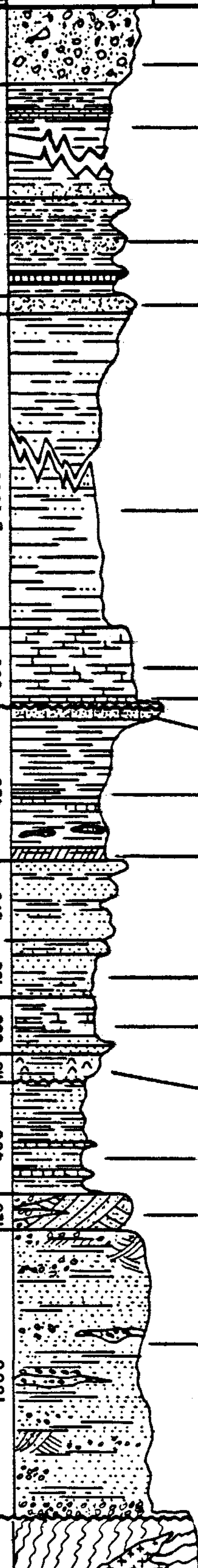
Figure 3-4: Structure of the Denver Basin

Denver Basin area (Kent, 1972). Middle Pennsylvanian orogenic activity formed the Ancestral Rockies, and the Fountain Formation was deposited unconformably on the uplifted Precambrian basement.

The sedimentary stratigraphic section in the vicinity of the Plant begins with the Fountain Formation (Figure 3-5), unconformably overlying the Precambrian metamorphics and dipping steeply to the east. The Fountain Formation contains coarse clastics derived from the erosion of the Ancestral Rockies and deposited as alluvial fans along the edge of the sea (Martin, 1965). The Fountain Formation is overlain by units resulting from sea transgressive and regressive sequences. The result was nonmarine sedimentation that occurred in northeastern Colorado from the Triassic to early Cretaceous. This sedimentation deposited a sequence of aeolian, fluvial-deltaic, and lacustrine units known as the Lyons, Lykins, Ralston Creek, Morrison, and Dakota Formations (Figure 3-5) (Kent, 1972).

The Pierre Shale, consisting of more than 5,600 feet of shales and siltstones, was deposited in the final phases of oceanic sedimentation. The sedimentation resulted from the last oceanic transgression occurring 100 million years ago during the late Cretaceous. This transgression formed an epicontinental sea called the Cretaceous Seaway that covered the eastern portions of New Mexico, Colorado, and Wyoming.

Following deposition of the Pierre, the ocean began to regress and deposition of the Upper Cretaceous Fox Hills and Laramie Formations occurred. These formations contain sandstones, siltstones, claystones, and coals deposited in fluvial-deltaic and lacustrine environments (Weimer, 1973). Deposition of the Laramie was influenced and then stopped by the Laramide Orogeny, a major mountain building



AGE		FORMATION	Thick (feet)	GRAPHICS	SUMMARY DESCRIPTION
TERTIARY		Green Mountain	600'		Boulder conglomerate with occasional thin siltstone lenses
TERTIARY		Denver-Arapahoe	1200'		Tan sandy claystone and clayey sandstone; conglomerate at base; includes Table Mountain "flow" rocks to the north
UPPER CRETACEOUS		Laramie	500'		Gray, fine-to-medium-grained sandstone and silty clays; thin coal beds in lower part
UPPER CRETACEOUS		Fox Hills	50'		Tan, fine-to-medium-grained sandstone and sandy shale
UPPER CRETACEOUS		Pierre	± 8000'		Dark gray, silty shale and few thin, silty sandstones
UPPER CRETACEOUS		Niobrara	350'		Dark gray, very calcareous shale. "Foraminifers" abundant (Smoky Hills Member) Light gray, dense, fossiliferous limestone(Fort Hays Member)
UPPER CRETACEOUS		Benton	420'		Brown, sandy, fossiliferous limestone Dark gray shale with bentonite streaks; thin limestones in middle part; few cone-in-cone concretions in lower part Dark gray, brittle silty shale (Mowry)
LOWER CRETACEOUS	Dakota Group	So. Platte	270'		Light gray, fine-to-medium-grained sandstone, several dark gray shales in middle part
LOWER CRETACEOUS	Dakota Group	Lytle	100'		Light gray, fine-to-coarse-grained, locally conglomeratic sandstone; frequent red and green siltstone interbeds
Jurassic		Morrison	365'		Gray to greenish-gray to red shale and siltstone; thin limestones in middle part; lenticular sandstones in upper and lower part
Jurassic		Ralston Creek	110'		Light tan siltstone and light red; silty shale; gypsiferous; sandstone at base and locally conglomeratic
Tri-assic? / PERMIAN		Lykins	400'		Red siltstone with two laminated limestones in lower part
PERMIAN		Lyons	120'		Grayish-white, fine-to-medium-grained cross-bedded sandstone; conglomeratic lenses frequent
PENNSYLVANIAN		Fountain	1000'		Red, fine-to-coarse-grained sandstone and conglomerate; arkosic; thin, lenticular red siltstones frequent throughout
PRECAMBIAN					Gneiss, schist, and small granitic intrusions

Figure 3-5: Generalized Stratigraphic Section, Golden-Morrison Area

(after: LeRoy and Weimer, 1971)

event that began in the late Cretaceous and caused uplift of the Colorado Front Range Mountains and the eastward tilting of the Denver Basin.

The Upper Cretaceous Arapahoe Formation was deposited on an erosional surface marking the end of deposition of the Laramie. Major uplift of the Front Range and downwarp of the Denver Basin continued during deposition of the Arapahoe Formation. Coarse pebble conglomerate lenses deposited in alluvial fans frequently occur in the Lower Arapahoe; however, conglomerate lenses were not found at the site. Claystone and sandstone units flank and top the alluvial fan deposits (Weimer, 1973).

The Denver Formation, deposited above the Arapahoe, resulted from volcanism associated with the Laramide Orogeny. This formation contains a variety of lithologies (siltstones, arkoses, conglomerates) up to 600 feet thick (Robson, 1984).

The Dawson Formation was deposited above the Denver in a similar geologic environment during the late Cretaceous and early Tertiary. Robinson (1972) described the Dawson Formation as a stratigraphic equivalent to the Denver Formation in southern portions of the Denver Basin. However, Robson (1984) mapped the Dawson as a separate, younger (Tertiary) formation occurring above the Denver. The Dawson is up to 600 feet thick and consists of conglomerates, sandstones, and shales (Robson, 1984).

The Tertiary Green Mountain Conglomerate was deposited unconformably on the Denver Formation, and consists of conglomerates, sandstones, siltstones, and claystones deposited by a local fluvial system that occurred only in the Golden, Colorado, area. This unit is only found capping Green Mountain, approximately 15 miles south of Rocky Flats Plant (Costa and Bilodeau, 1982).

The Rocky Flats Alluvium was deposited on top of a major erosional surface that developed in late Tertiary time. Before deposition of the Rocky Flats Alluvium, both the Dawson and Denver Formations were completely removed by erosion. The Green Mountain Conglomerate may never have been deposited at the site, but if it was, it also was removed by erosion. The Rocky Flats Alluvium contains boulders, cobbles, gravels, sands, silts, and clays deposited in alluvial fans at the base of the Colorado Front Range Mountains (Hurr, 1976).

Following deposition of the Rocky Flats Alluvium, the material was partially removed by erosion and the resulting drainages repeatedly infilled with more recent sediments. The Verdos Alluvium and the younger Slocum Alluvium are the result of drainage infilling in association with glacial activity. Similar processes are occurring now with an active valley fill alluvium in the stream channels and a recent but stable terrace above the valley fill.

3.6.2 Plant Bedrock Geology

Bedrock units mapped at the Plant during the 1986 initial site characterization consist of the Laramie and Arapahoe Formations (Figure 3-6). Because of the thickness (750 to 800 feet) and low permeability of the Upper Laramie, it is considered to be the base of the hydrologic system which could be affected by Plant operations. The Upper Laramie and overlying Arapahoe Formations are described below.

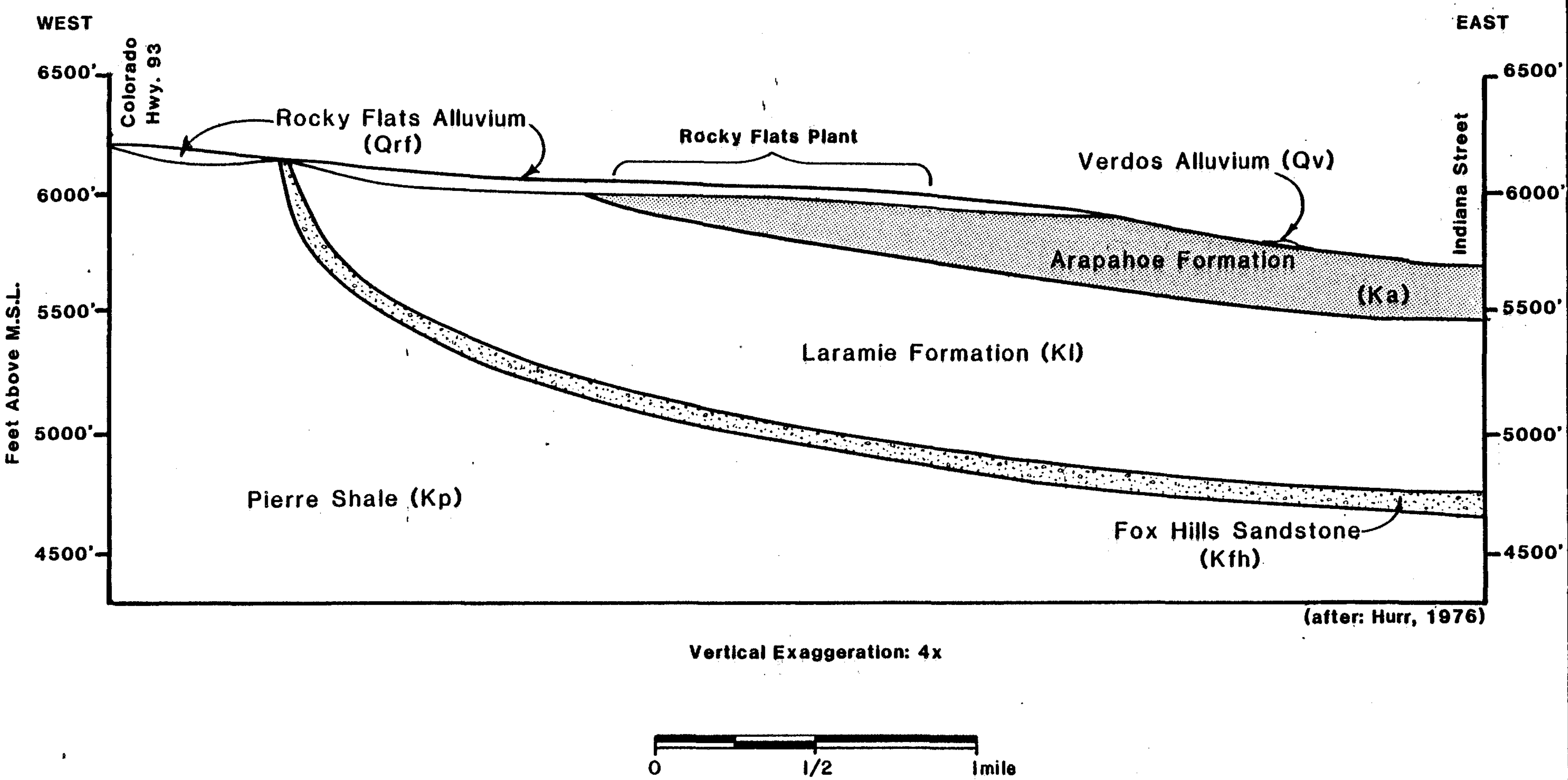


Figure 3-6: Generalized Cross Section of Rocky Flats Plant

Laramie Formation

The Laramie Formation is a fluvial sequence of sandstones, siltstones, claystones, and coals, which is subdivided into two major lithologic units: a lower sandstone unit and an upper claystone unit. The lower sandstone unit is exposed in clay pits west of the plant, and the upper claystone unit was observed in outcrop and in cores of several 1986 monitor wells west of the Plant. The descriptions presented below are taken from Rockwell International (1986a).

> Lower Sandstone Unit: The lower sandstone unit consists of light to medium gray, very fine- to medium-grained, well sorted, subrounded to subangular quartzose sand with up to 25% lithic fragments. Sandstones are typically fair to poorly indurated and cemented with silica. Individual sandstone beds are 5 to 15 feet thick and are interbedded with white to light gray claystones. The claystones are organic-rich and kaolinitic and have been mined from the clay pits west of the plant. Individual claystone beds are 10 to 15 feet thick. Sedimentary structures observed in outcrop include planar, angular, and trough crossbeds, load structures, fluid escape structures, and ripple marks. Plant fossil casts and molds of branches, stems, and leaves are concentrated along bedding planes. The contact between the lower sandstone unit and the upper claystone unit is gradational and was selected where thick sandstone beds and kaolinite-rich claystones are less abundant.
>
> Upper Claystone Unit: The upper claystone unit consists primarily of dark olive gray (5 Y 2/1) (GSA Rock Color Chart), poorly indurated claystones. Upper Laramie claystones generally weather to a light olive gray (5 Y 4/1) and may have dark yellowish orange (10 YR 6/6) iron staining along bedding planes and secondary fractures. These claystones appear quite similar to Arapahoe claystones in outcrop.
>
> Thin sandstone lenses (less than three feet thick) also occur in the upper Laramie. These sandstones are typically yellowish gray (5 Y 8/1), fine- to very fine-grained, well sorted, subangular, and calcareous. Core data (well 50-86) indicate that thin beds of white,

kaolinite-rich claystone typical of the Lower Laramie occur in the Upper Laramie as well.

The contact between the Upper Laramie claystones and the Lower Arapahoe sandstones is gradational and was selected using core data. The contact was picked below the first Arapahoe sandstone greater than five feet thick (Rockwell International, 1986a).

Arapahoe Formation

The Arapahoe Formation consists of fluvial claystones with interbedded lenticular sandstones and siltstones. Contacts between these lithologies are both sharp and gradational. The claystones are olive gray (5 Y3/2) to dark gray (N 3/0), poorly indurated, silty, and contain up to 15 percent organic material. Weathering has penetrated to depths ranging from 10 to 40 feet below the base of surficial materials. The weathered claystone is light olive gray, blocky, slightly fractured, and has iron staining as mottles and along bedding planes and fractures (Rockwell International, 1986a).

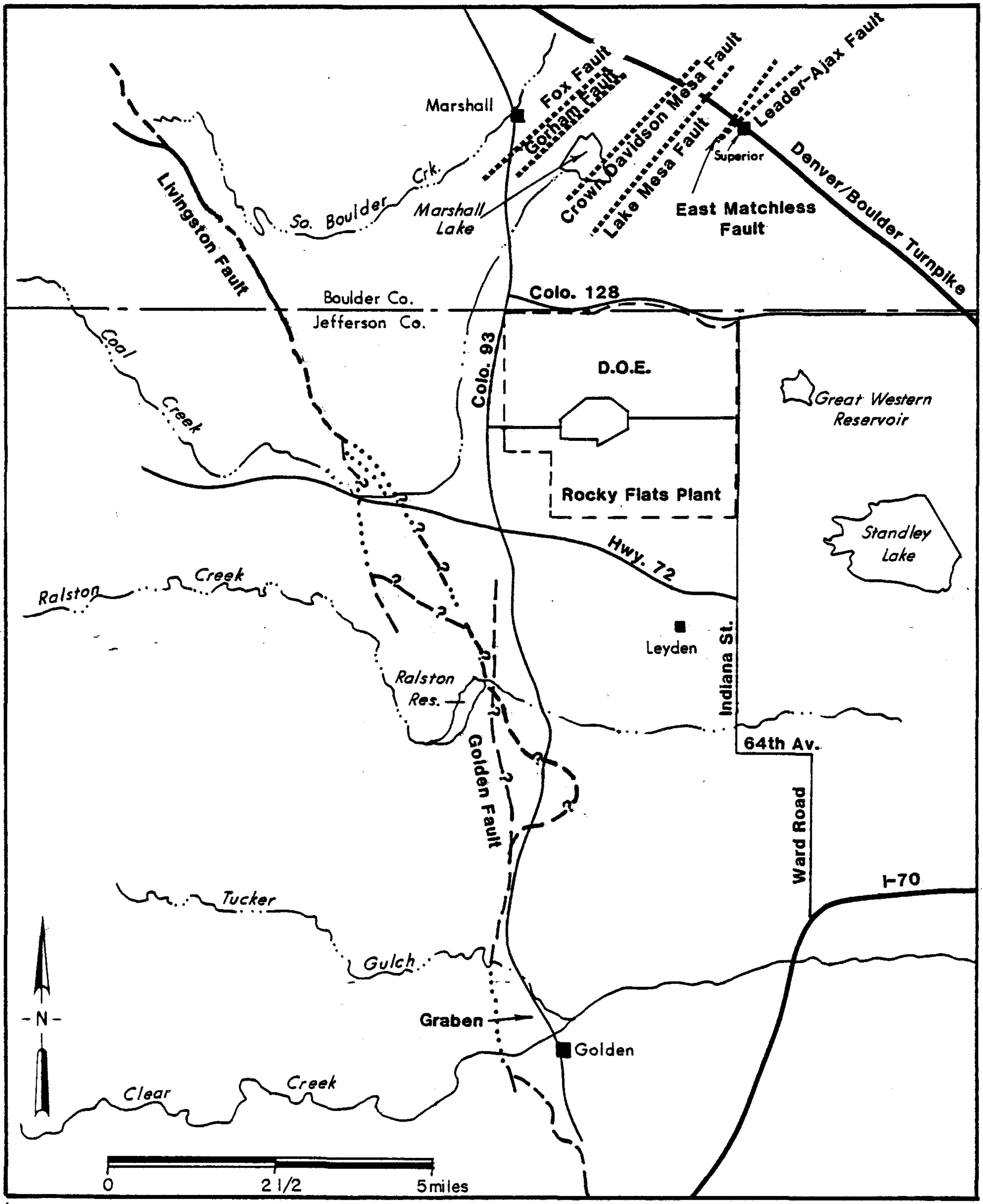
Sandstones in the Arapahoe Formation are light gray (N 6/0) to yellowish gray (5 YR 8/1), very fine- to medium-grained, with approximately 15 percent silt and clay. The sandstones are lenticular, discontinuous, and stratigraphically complex. The sand grains are subangular to subrounded and are predominantly quartzose with 10 percent lithic fragments. The sandstones are poorly to moderately cemented and exhibit ripple marks, load casts, and planar, angular, and trough crossbedding. Arapahoe Formation siltstones exhibit the same coloration, constituents, bedding characteristics, and sedimentary structures as the sandstones; however, they consist predominantly of silt-sized particles (Rockwell International, 1986a).

3.6.3 Regional Bedrock Structure

The general geologic structure of the area is north-striking sedimentary beds with dips to the east away from the Front Range Monocline. Dips are quite steep west of the Plant in the Fox Hills Sandstone and Laramie Formation (on the order of 50 degrees or greater). These units are flanked on the west by Precambrian terrain of the Front Range Uplift and on the east by gently dipping sedimentary beds of the Denver Basin. However, because the axis of the monocline onto the Front Range appears to be inclined to the east, dips become rapidly more gentle, on the order of 7 to 15 degrees beneath the Plant itself (Rockwell International, 1986a). A major bounding fault between the Front Range and the Denver Basin, the Golden Fault, runs north-south several miles west of the Plant at the mountain front (Van Horn, 1972)(Figure 3-7).

The majority of the displacement on the Golden Fault, the uplift of the Front Range and subsidence of the Denver Basin, occurred during the late Cretaceous to early Eocene Laramide Orogeny about 40 to 70 million years ago (Martin, 1965). Erosion during the Laramide Orogeny is believed to have kept pace with uplift and the Front Range probably never stood very high above the Denver Basin during the orogeny. By the late Eocene, an erosional surface of the low relief covered much of the Rocky Mountain Region.

The present rugged topography to the west of the Rocky Flats Plant is the result of Post-Laramide tectonics and erosion. About 5,000 to 10,000 feet of uplift has taken place in the Rocky Mountain Region since the early Miocene about 25 million years ago. Late Tertiary block faulting is believed to have accompanied the



(after: Van Horn, 1972, Sheridan and others, 1967, Wells, 1967, and Spencer, 1961)

Figure 3-7:
Fault Locations Between Golden and Marshall, Colorado (excluding Eggleston Fault)

regional uplift as indicated by apparent displacements of the late Eocene erosional surface (Scott, 1975 and Epis and Chapin, 1975). There is some evidence that block faulting has continued into the Quaternary (Scott, 1970; Whitkind, 1976; and Kirkham and Rogers, 1981).

In 1981, extensive studies were done to evaluate the Quaternary history of the Golden Fault and other faults at the Rocky Flats Plant and vicinity (Dames and Moore, 1981). The Golden Fault studies did not produce any evidence of tectonic activity along the Golden Fault within the past 500,000 years, and the fault does not have surficial expressions characteristic of geologically young fault zones.

Hurr (1976) showed a fault crossing the eastern edge of the Plant, based on a series of bedding irregularities that appeared to be an extension of the previously mapped Eggleston Fault (northwest of the site). Further investigations of the feature (Dames and Moore, 1981) revealed that it is probably a penecontemporaneous growth fault attributed to slumping of the unconsolidated Arapahoe Formation before burial and lithification. The Denver Basin has been tectonically stable for about 28 million years with the exception of a series of earthquakes associated with waste injection at the Rocky Mountain Arsenal in the 1960s and possible surface rupture on the Golden Fault approximately 600,000 years ago (Kirkham and Rogers, 1981).

3.6.4 Regional Ground-Water Hydrology

The Denver ground-water basin underlies a 6,700 square mile area extending from the Front Range on the west to near Limon, Colorado on the east and from Greeley on the north to Colorado Springs on the south. The four major bedrock aquifers occurring in the basin from deepest to shallowest are the Laramie-Fox Hills

Aquifer, the Arapahoe Aquifer, the Denver Aquifer, and the Dawson Aquifer. The Pierre Shale underlies these units and is considered the base of the bedrock aquifer system due to its great thickness (up to 8000 feet) and its low permeability (Robson and others, 1981a).

Presented below are discussions of the two Denver Basin bedrock aquifers which occur beneath Rocky Flats Plant - the Laramie-Fox Hills Aquifer and the Arapahoe Aquifer. The Denver and Dawson Aquifers do not occur in the immediate vicinity of Rocky Flats Plant.

Laramie-Fox Hills Aquifer

The Laramie-Fox Hills Aquifer is composed of the upper sandstone and siltstone units of the Fox Hills Formation and the lower sandstone units of the Laramie Formation. The thickness of the aquifer ranges from zero near the aquifer boundaries to 200 to 300 feet near the center of the basin. The upper Laramie coals and claystones separate the Laramie-Fox Hills Aquifer from the overlying Arapahoe Aquifer (Robson and others, 1981b).

There are three primary methods of ground-water recharge to the Laramie-Fox Hills Aquifer. In outcrop and subcrop areas recharge occurs as infiltration of incident precipitation and as infiltration from shallow alluvial aquifers. In the central part of the basin recharge occurs as leakage through the upper Laramie Formation from overlying bedrock aquifers (Robson and others, 1981b). The Laramie-Fox Hills outcrops in clay pits west of the Plant are recharge areas of the aquifer.

On a regional scale ground-water in the Laramie-Fox Hills Aquifer flows from outcrop recharge areas toward the center of the basin and discharges to remote stream valleys. In addition, ground water discharges to pumping wells in the basin (Robson and others, 1981b). In the vicinity of Rocky Flats Plant ground-water flow is generally from the west to the east (Figure 3-8).

Arapahoe Aquifer

The Arapahoe Aquifer is defined as the saturated portion of the Arapahoe Formation by Robson and others (1981a). The Arapahoe Formation consists of a 400 to 700 foot thick sequence of interbedded claystones, siltstones, sandstones, and conglomerates with claystones and shale being more prominent in the northern third of the basin (Robson and others, 1981a). Individual sandstone beds are commonly lens shaped and range from a few inches to 30 to 40 feet in thickness (Robson and others, 1981a). Beneath the Plant the majority of ground-water flow in the Arapahoe is in the lenticular sandstones contained within the claystones (Rockwell International, 1986a).

Recharge to the Arapahoe Aquifer occurs by the same mechanisms as those described for the Laramie-Fox Hills Aquifer. In outcrop and subcrop areas it occurs from infiltration of incident precipitation and as infiltration of water from shallow alluvial aquifers. However, on a regional scale the primary recharge mechanism for the Arapahoe Aquifer is leakage from the overlying Denver Aquifer (Robson and others, 1981a).

Ground-water flow in the Arapahoe Aquifer is from recharge areas at the edges of the basin toward discharge areas along incised stream valleys. Ground-water is also discharged to pumping wells (Robson and others, 1981a). Ground-water flow in the vicinity of Rocky Flats Plant is from west to east toward the area of regional discharge along the South Platte River (Figure 3-9).

3.6.5 Plant Surficial Geology

There are six distinct Quaternary unconsolidated units of surficial materials in the vicinity of the Plant: Rocky Flats Alluvium, Verdos Alluvium, Slocum Alluvium, terrace alluviums, valley fill alluvium, and colluvium (Figure 3-10).

The Rocky Flats Alluvium is topographically the highest and the oldest of the alluvial deposits. The alluvium unconformably overlies the Laramie and Arapahoe Formations in the vicinity of the Plant. The deposit is a series of laterally coalescing alluvial fans deposited by streams (Hurr, 1976). The fans were deposited on an erosional surface cut into the bedrock units, including channelization around the hogbacks of the lower Laramie.

The alluvium consists of sand, clay, silt, gravel, cobble, and occasional boulder deposits. Locally, the alluvium is cemented with calcium carbonate in the form of caliche. Color of the alluvium is pale to dark yellowish brown. The sands range from very fine-grained to medium-grained and poorly to moderately sorted. The thickness of the alluvium is variable due to deposition on an erosional surface and recent erosional processes. The alluvium is thickest to the west of the Plant, where less has been eroded, and thinnest to the east of the Plant (Rockwell International, 1986a).

Various alluvial deposits occur topographically below the Rocky Flats Alluvium in the drainages and include the Verdos, Slocum, terrace, and valley fill

YEARS before present	EPOCH	GLACIAL SEQUENCE		DEPOSIT				
1000	HOLOCENE	Gannett Peak Stade	"Valley Fill"	post-Piney Creek Alluvium	young alluvial fan	colluvium and landslides	loess and eolian sand
2000		Interstade		(Soil)			
3000		Temple Lake Stade		Piney Creek Alluvium			
5000		"Altithermal Interval"		(Soil) pre-Piney Creek Alluvium			
12,000	PLEISTOCENE	WISCONSIN Pinedale Glaciation	Terrace Alluvium	(Soil) Broadway Alluvium	old alluvial fan		
60,000		WISCONSIN Bull Lake Glaciation		Louviers Alluvium			
130,000					?		
250,000		Sangamon Interglaciation / ILLINOIAN		(Soil) Slocum Alluvium	?	?	
600,000		Yarmouth Interglaciation / KANSAN		(Soil) Verdos Alluvium	?	?	
1,000,000		Aftonian Interglaciation / NEBRASKAN		(Soil) Rocky Flats Alluvium	?	?	
1,500,000	Pleistocene or Pliocene			Pre-Rocky Flats Alluvium			

(after: Van Horn, 1976, and Scott, 1965)

Figure 3-10:
Surficial Alluvial Deposits in the Rocky Flats Area

alluviums and colluvium (Figure 3-11). These deposits are primarily composed of reworked Rocky Flats Alluvium with the addition of some bedrock material. Each unit is described below.

The Verdos Alluvium occupies a topographic position about 0 to 100 feet below the adjacent top of the Rocky Flats Alluvium. The Verdos was deposited around the periphery of the present extent of the Rocky Flats Alluvium as fans and channel filling derived by erosion of the older Rocky Flats Alluvium. The maximum thickness is about 40 feet, occurring as terraces in valleys east of the Plant. The alluvium consists of unsorted gravels, sands, and clays similar to the Rocky Flats Alluvium, but the material is whitish gray in color (Rockwell International, 1986a).

The Slocum Alluvium is a poorly sorted gravel deposit containing much sand, silt, and clay derived from erosion of bedrock and the older gravel deposits. The formation has a maximum thickness in the vicinity of the Plant of about 20 feet, but is commonly 5 to 10 feet thick. It occupies a topographic position of about 150 to 300 feet below the top of the Rocky Flats Alluvium, and occurs downslope of the Verdos Alluvium in valleys east of the Plant site (Rockwell International, 1986a).

Locally, two Wisconsin-age terraces are associated with the present drainages. The terrace alluvium occurs 5 to 35 feet above recent valley floors. The alluvium is comprised of gravels, sands, and clays, derived from bedrock and reworking of older alluvial deposits. The terrace alluvium can rarely occur up to 30 feet in thickness; however, the thickness is usually around 5 feet. The alluvium occurs in valleys surrounding the Plant (Rockwell International, 1986a).

Valley fill alluvium occurs in the bottom of the present stream valleys around the Plant. The valley fill ranges from dark-brown, sandy, clayey silt to moderately

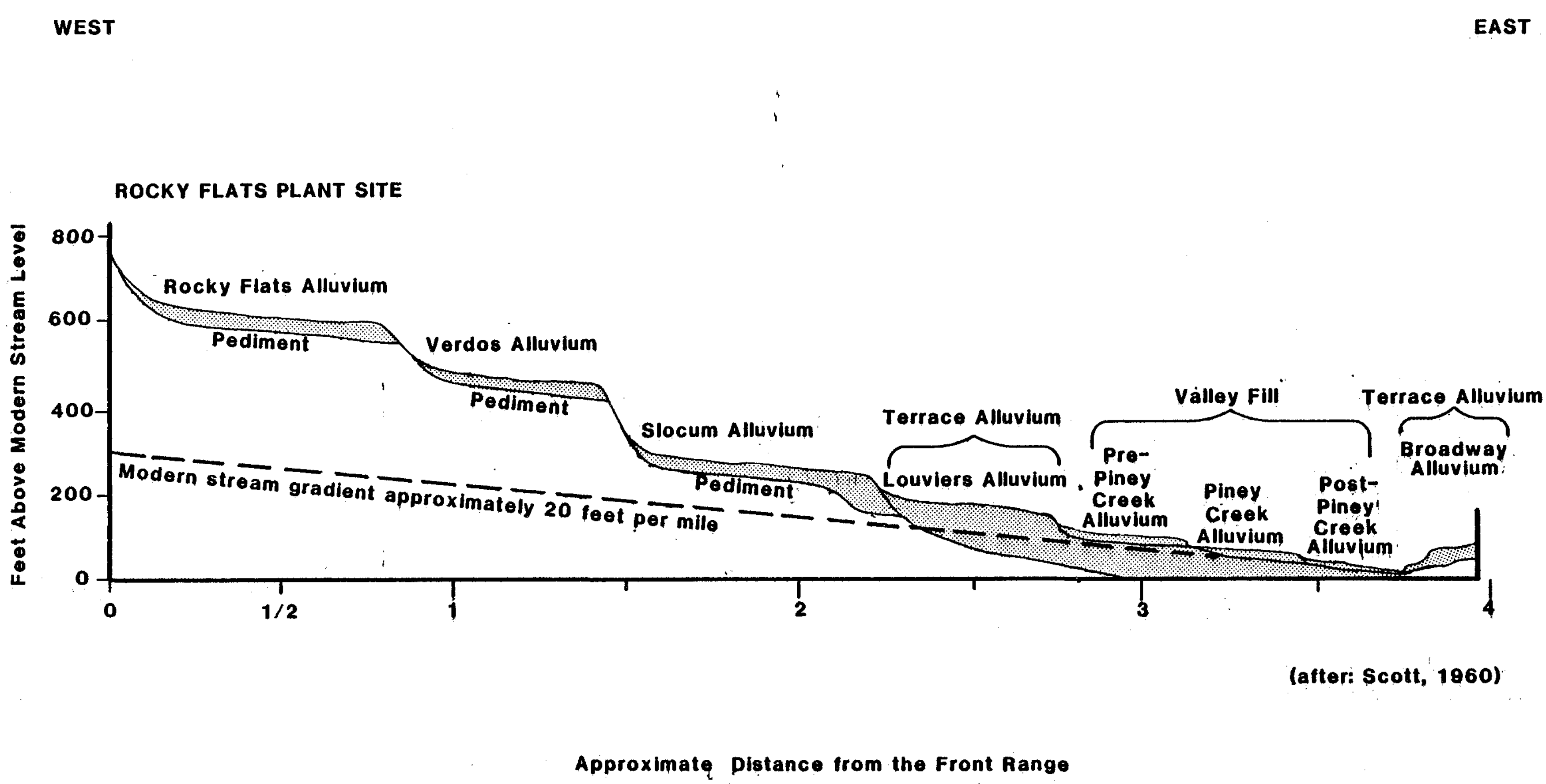


Figure 3-11:
Erosional Surfaces and Alluvial Deposits East of the Front Range, Colorado

sorted cobbles and small boulders, recently reworked from previously deposited alluviums. The valley fill along streams which head on the Rocky Flats Alluvium and have not yet cut through to bedrock tends to be coarse and have little or no fine material. However, where the valley fill is deposited on bedrock, 0.5 to 2 feet of cobbly sand and gravel commonly is overlain by several feet of sandy, clayey silt (Rockwell International, 1986a). Subsequent erosion and deposition locally may have added more sand, gravel and cobbles on top of the silt, or cut through the valley fill to expose bedrock along the channel bottom (Hurr, 1976).

Colluvium, produced by mass wasting and downslope creep, collects on the sides and at the base of hills and slopes. These deposits are poorly sorted mixtures of soil and debris from bedrock clay and sand mixed with gravel and cobbles derived from the older Rocky Flats Alluvium. The colluvium consists predominantly of clay with common occurrences of sandy clay and gravel. Color is yellowish brown to dusky brown and caliche is common locally. The thickness of the colluvium ranges from 3 to 22 feet (Rockwell International, 1986a).

3.7 WATER RESOURCES

3.7.1 Surface Water Resources

Surface waters in the vicinity of the Plant supply water to two reservoirs used for municipal water supply and recharge aquifers used for domestic water supply. There are six streams in the general area (Figure 3-12): North Walnut Creek, South Walnut Creek, Woman Creek, Coal Creek, Rock Creek, and Leyden Gulch. All of the streams are intermittent. The Walnut Creeks deliver flow into Great Western Reservoir, and Woman Creek delivers water to Mower Reservoir and Standley Lake.

In addition to the natural flows, there are five ditches in the general vicinity of the Plant. The Church and McKay Ditches (diversions of Coal Creek) cross the Plant. Church Ditch delivers water to Upper Church Lake and Great Western Reservoir (City of Broomfield municipal water storage). McKay Ditch also supplies water to Great Western Reservoir. Last Chance Ditch flows south of the Plant and delivers water to Rocky Flats Lake and Twin Lakes. Smart Ditch takes water from Rocky Flats Lake and transports it out of the area to the east. The South Boulder Diversion Canal runs along the west edge of the Plant diverting water from South Boulder Creek and delivering it to Ralston Reservoir (City of Denver municipal water storage).

3.7.2 Ground-Water Resources

Usable ground water occurs in both the Laramie-Fox Hills and Arapahoe Aquifers. The Laramie-Fox Hills subcrops west of the Plant but has little potential for use in the general area because of its great depth (approximately 750 to 800 feet deeper than the Arapahoe). Various sandstones in the Arapahoe Aquifer are used for irrigation, livestock watering, and domestic purposes east of the Plant. Water wells within three miles of the Plant are listed in Table 9-1 and discussed in Section 9.0.

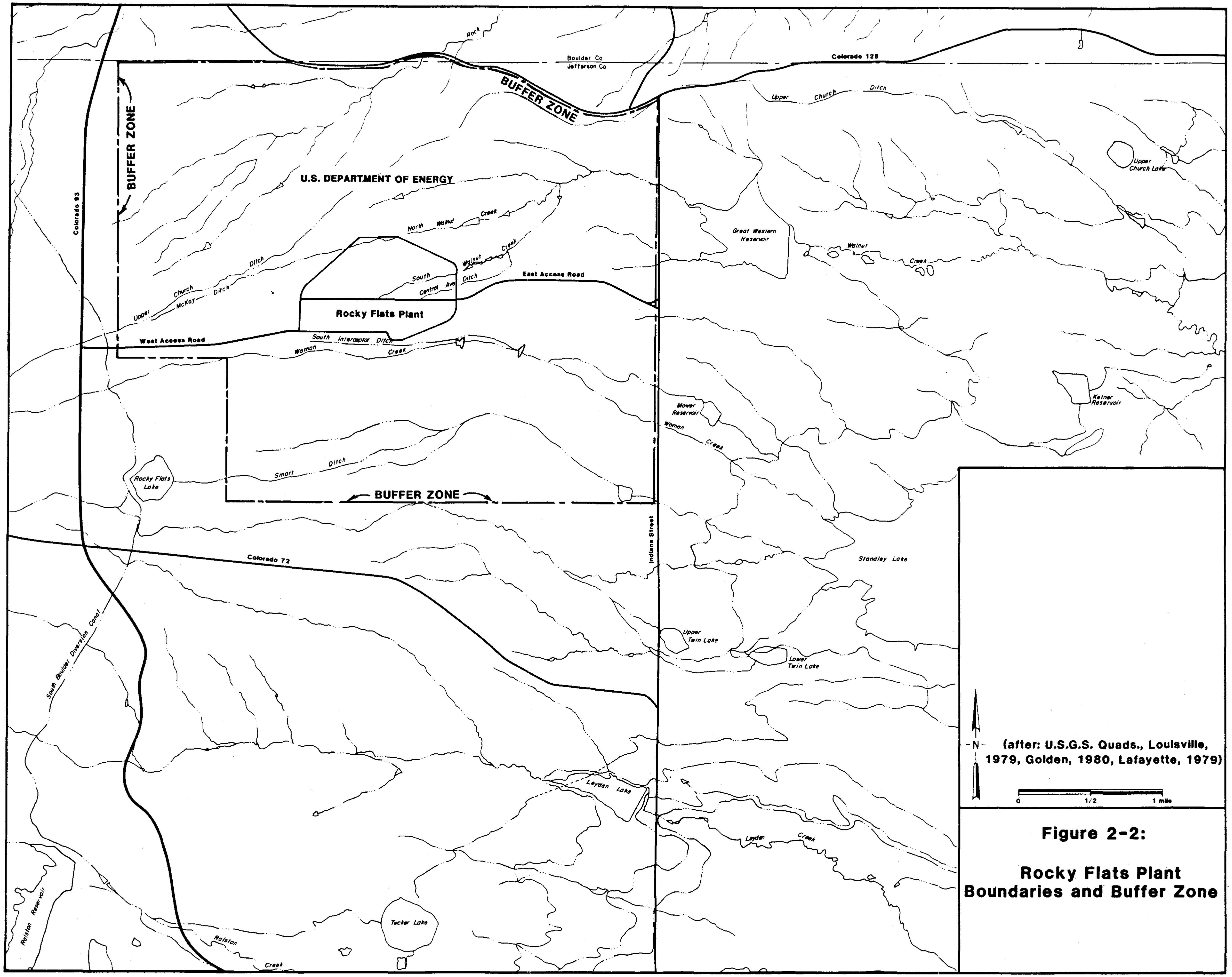


Figure 2-2:

Rocky Flats Plant Boundaries and Buffer Zone

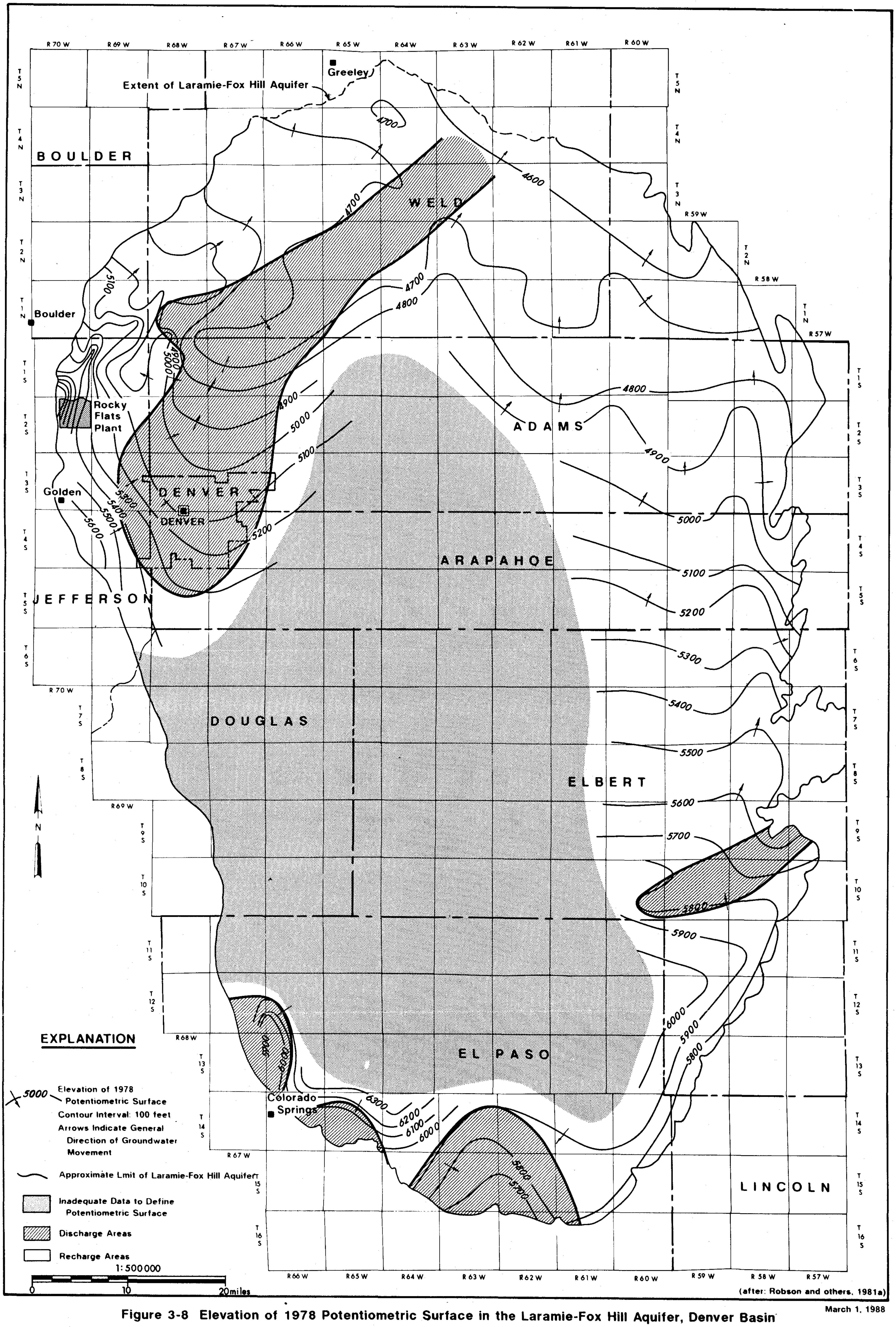


Figure 3-8 Elevation of 1978 Potentiometric Surface in the Laramie-Fox Hill Aquifer, Denver Basin

March 1, 1988

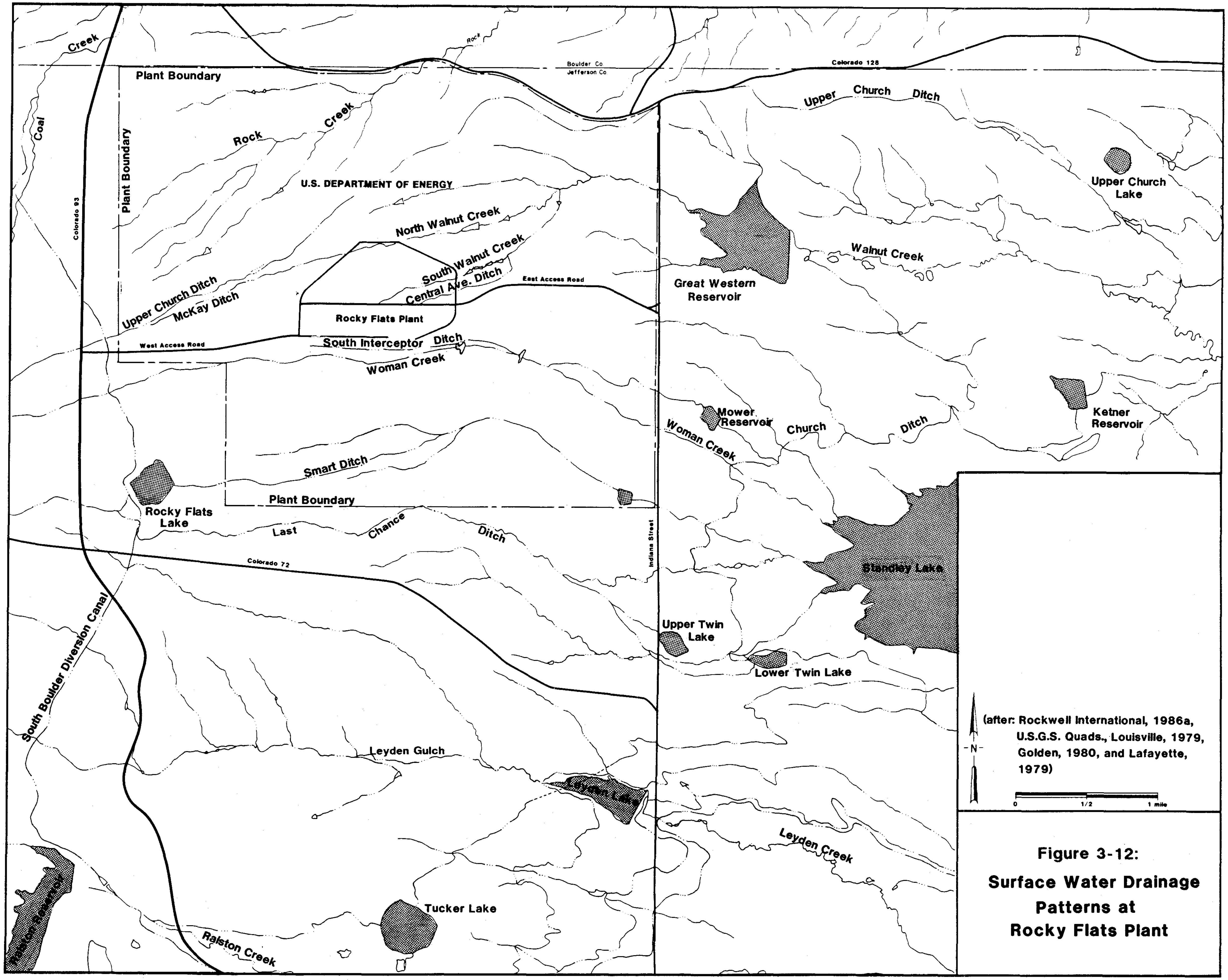
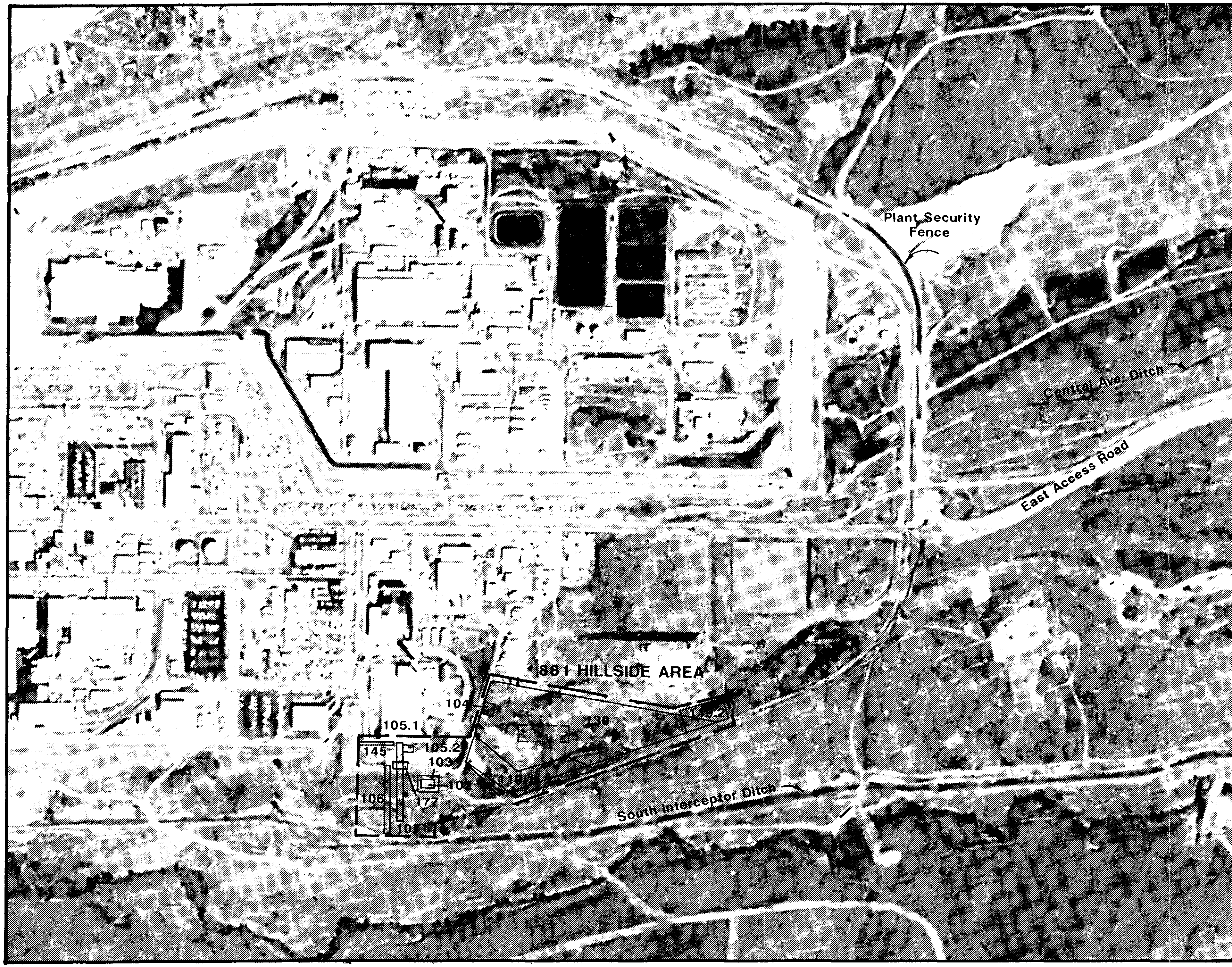


Figure 3-12: Surface Water Drainage Patterns at Rocky Flats Plant



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EXPLANATION:

☐ Location of Solid Waste Management Unit

⌜⌟ Location of Areas of Interest Within Solid Waste Management Unit

101 Solid Waste Management Unit Reference Number (Rockwell International, 1986a)

NOTES:

1) Base map photo-enlarged from aerial photography of Rocky Flats Plant taken May 20, 1986.

2) The locations of the solid waste management units have been located as accurately as possible, based on information available prior to 1987 remedial investigation.

1"=500'

0 500' 1000'

Figure 2-3: Remedial Investigation Area Locations and Associated Solid Waste Management Units

March 1, 1988